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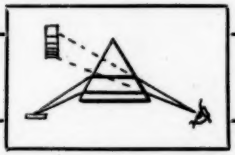

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THE PROJECTION OF PARALLAX PANORAMAGRAMS

By Herbert E. Ives
[Bell Telephone Laboratories, New York, N. Y.] Received March 21, 1931]

The relief pictures of the parallax panoramagram type, which exhibit stereoscopic relief through a wide range of angles and distances, as heretofore described,[1] are in the form of transparencies or reflecting pictures suitable for placing before a light source or holding in the hand. The question is frequently raised whether parallax panoramagrams could not be projected upon a screen, presumably to a large enough size to be seen by a considerable group of spectators. The answer, in general terms, has always been in the affirmative, with certain qualifications having to deal with the difficulties and the obstacles to satisfactory results.

One of these difficulties is that the opaque line grating, which has been most commonly used in parallax panoramagrams, has a very low transmission, so that a great deal of light would be required for satisfactory results. Another difficulty is that it will unquestionably be a matter of extreme nicety of optical definition and registration to project the panoramic strips upon the appropriate elements of the screen, whatever form the latter may take.

The chief purpose of this paper is to describe an experimental arrangement and procedure which has proved successful, even though on a somewhat crude scale, in producing relief pictures by projection. The

[1] Vide J.O.S.A., Oct. 1930, p. 585 and references therein.

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most important feature of this method is a type of projection screen which is not wasteful of light, by the use of which the first mentioned difficulty has been overcome. The second difficulty appears to be fundamental, but is not beyond solution, at least with the grain of picture used in these experiments, by proper choice of optical elements in the projector and of careful construction of the apparatus.

The projection screen is a transmission screen whose minute structure is essentially that used in the production of parallax panoramagrams for

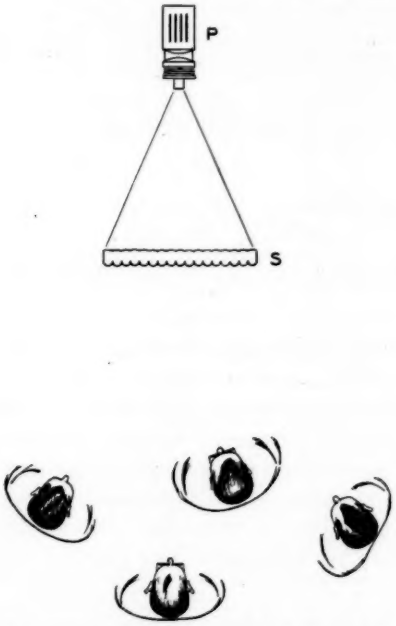

FIG. 1. *Principle of ridged transmission screen for projecting parallax panoramagrams.*

viewing by reflected light, as described in a recent paper.[1] A characteristic of the double ridged structure there described is that parallel rays incident on the front curved surface are brought to an accurate focus upon the rear curved surface. Consequently, an observer looking at the front surface from any direction receives light only from a narrow line upon the rear surface. In the application of this idea to a projection screen, the rear surface is no longer provided with a fixed picture on a photographic emulsion, but is merely given a diffusing finish. The effect of this finish is to diffuse the light along the length of the ridged

element so that a bright point on the rear surface may be seen from all positions in a narrow sheet extending out from the front surface. If now, in place of the photograph which is permanently in place on the rear ridges in the case previously described, we have an image of a panoramic strip projected upon a component element of the ridged surface, the observer in front will see a different linear element of the panoramic strip from every lateral position of observation. The problem thus resolves itself into the production of a suitable double ridged surface and a feasible method of projecting, upon the rear of this surface,

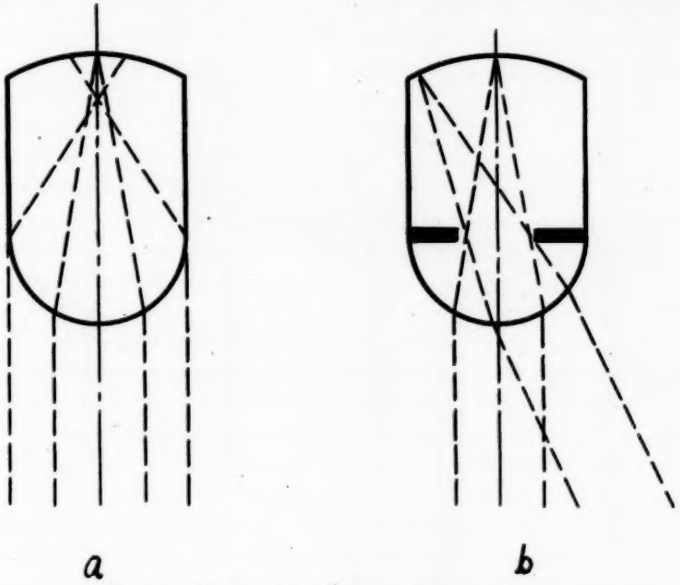

FIG. 2. *Sections of rod elements used in transmission screen.*

the image of a parallax panoramagram transparency of the same sort as would ordinarily be mounted behind an opaque line grating. The general arrangement will be clear from the diagrammatic representation in Fig. 1.

The scheme adopted for making a screen in these experiments was to build it out of rods of celluloid, which were machined to the right shape and were subsequently polished on their front surfaces, sand blasted on their rear surfaces, and given a coating of opaque black paint on their sides. An enlarged sectional view of one of these rods is shown in Fig. 2a. The elements used were cut from celluloid sheet 1/8 inch thick, the

original faces of the sheet forming the sides of the rod. The refractive index of the celluloid was very closely 1.5, so that in accordance with the theory given in the paper above referred to, the radius of curvature of the front, polished, surface was 1/16 inch, and of the rear, sand blasted surface, 1/8 inch. The curvatures were produced by passing the strips through a milling machine provided with curved cutters and the polishing operation was found to be most easily done by dipping the rod for an instant in acetone. The complete screen contained 200 of these rods, each 2 feet long, which were pressed tightly together, giving a screen approximately 2 feet square.

The picture used for projection consisted of a positive print from a parallax panoramagram negative, which was made by a moving lens camera of the type described in a previous article.[2] The opaque line grating used in this camera had 50 lines to the inch, the clear spaces being 1/10 the width of the opaque. The print was made on a lantern slide plate in order to permit projection by means of a lantern slide projector whose field was something over 3 inches wide, so that upon the appropriate magnification to register the panoramic elements upon the ridges of the screen, a considerable part of the screen area was utilized.

It is obvious that very accurate imaging and registration of the panoramic strip elements upon the screen ridges is essential. In order to accomplish this, the regular lens of the projector was removed and in its place was inserted a high quality Tessar photographic lens of 6 inch focus. The picture to be projected was mounted on a flat glass plate which was held by two springs, permitting the picture to be moved easily in any desired direction by hand. The lantern itself was mounted upon a track so that it could be moved smoothly forward and back, and the projection lens had a fine rack and pinion adjustment. The operation of securing the exact registration of a picture upon the screen then consisted of successive trials of various positions of the lantern, at each of which the image was accurately focused, with a careful adjustment of the level of the picture so that its strips were parallel to the rods in the screen. An additional necessary adjustment is one for moving the image laterally in respect to the screen, since while variation of the level of the parallax panoramagram is easy by hand, a lateral shift of only a fraction of a fiftieth of an inch is quite difficult. This lateral adjustment was provided in the present case, by moving the whole screen on its support by means of a large screw. The apparatus as set up is shown in Fig. 3.

[2] J.O.S.A., Dec. 1928, p. 435.

Experimental tests proved that the defining power of the lens was adequate and that the figure of the curved faces of the rods was sufficiently good to give a very striking relief picture of large size, showing the characteristic properties of the parallax panoramagram. The image shows stereoscopic relief, and if the observer moves from one side of the normal to the screen, to the other, he sees different sides of the object.

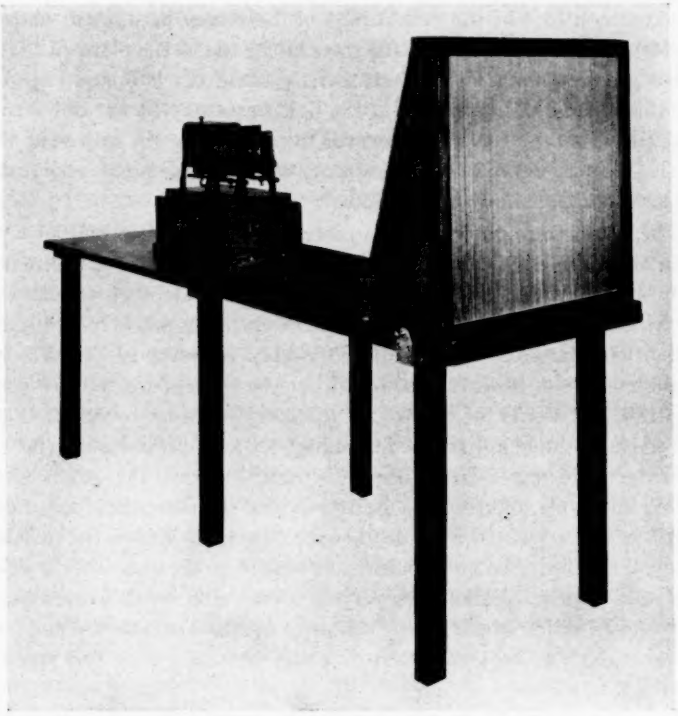

FIG. 3. *Apparatus used in experimental demonstration of relief projection.*

Certain details of the projection screen structure may be mentioned before proceeding to the discussion of other projection schemes and problems. The form of rod which has been constructed is subject to certain defects, which impair the perfection of the relief image. These defects are to be ascribed in part to the imperfect figure of the machined and polished surfaces, and in part, probably, to striations or other irregularities in the composition of the material. A defect, not of work-

manship, but of a more fundamental nature, is a spreading of the refracted light, due to spherical aberration in the rods. This is shown in Fig. 2*a*, where the paths of the more extreme rays leaving the rod in a parallel beam are shown as deviated from their proper focus. In order to avoid this, the rods should be diaphragmed to a smaller diameter. This must be done in such a way, however, as not to decrease the angular field. For this purpose, the diaphragm should lie in the plane of the common axis of the two surfaces. This may be done as shown in Fig. 2*b* by cutting grooves in the sides of the rod in the plane of the axis, these grooves being filled afterward by some black opaque material. By this means, the spreading of the light rays may be cut down to any desired extent, at the cost, however, of narrowing the apparent width of the rods as viewed from the front, with a consequent accentuation of the lined appearance of the picture.

The angle through which the picture may be seen is limited, as has been shown in a former paper,[1] by the refractive index of the material from which the rods are made. In place of the machined celluloid rods for which this angle is 60°, it would be desirable in many respects to use rods of circular cross-section, drawn in glass of refractive index 2. The possible angle of observation would here be (except for mutual screening) 180°. It would, of course, be necessary, in order to utilize this entire angle, to have apparatus for taking the original negatives through the same wide angle. If smaller angle pictures are all that are available, the circular rods could still be used, provided the panoramic strips of the negative are separated by a dead space corresponding to the deficiency in angle covered. An outstanding advantage of the glass rods would be that they naturally assume a very accurate circular cross-section and high polish, which would promise more accurate separation of the beams of light leaving the screen than is easily attained with the machined celluloid.

As above stated, the picture used in these projection experiments was a parallax panoramagram made with the lever type of moving lens camera. This is one of several types of camera which might be used, all of which involve moving parts and rather long overall exposure times.[3] It would be highly desirable to make these pictures by some scheme requiring relatively short single exposures, such, for instance, as the use

[3] Another method of making pictures for projection in this manner is to use a battery of many juxtaposed cameras, and to photograph the image displayed on the back of a ridged screen when the negatives made in these cameras are projected from a battery of projectors. (J.O.S.A. Feb. 1929, p. 118.)

of a large diameter lens or concave mirror, as described elsewhere.[4] There are, however, two obstacles to the use of the large diameter lens or mirror. One is that the pictures as obtained are too large for use in a projection lantern. This is because the large lens or mirror, if wide enough to give a useful range of angles of observation, is of necessity of such long focus that images of objects like a human head must be made practically life size. A second obstacle is that the panoramic negatives, as obtained from such apparatus, have the elementary strip images so oriented that the resultant picture, as reconstructed through a grating placed between the eye and the picture, exhibits inverted or pseudoscopic relief. This may be overcome, in the case of the picture as ordinarily mounted, by placing the grating behind the picture.[5] This subterfuge is not available in the projection method above described. The parallax panoramagrams must be of the orientation suitable for viewing *through* the grating.

Both of these obstacles can be overcome by the introduction of additional operations, and changes in the structure of the ridged screen. The difficulty of size may be met by printing the parallax panoramagram negative to a reduced scale by means of a copying camera with a high quality photographic lens. If this lens is substantially identical with that used for the subsequent projection, its errors will be compensated out. Instead of making this reduction to lantern slide size as a special operation in a copying camera, it is a more attractive idea to do this in the original exposure. Thus, let us suppose the large photographic plate behind the grating replaced by a diffusing screen such as ground glass. If now, an image of this ground glass is formed by the high quality photographic lens onto a photographic plate at a suitable distance, a reduced sized image is obtained at one operation. This procedure is shown in Fig. 4, when L_1 is the large diameter lens, L_2 the photographic lens and F is the sensitive plate. If a grating and ground glass are used this method is quite wasteful of light, but if a screen similar to the projection screen above described is used, as shown at S this objection may be largely removed. Whichever way the picture of reduced size is made, the grating or equivalent structure used with the large lens or mirror must, of course, be of much coarser spacing than that called for in the lantern slide to be used for projection.

The second difficulty, that of inverting the panoramic strips of the negative, obtained with a large lens or mirror in conjunction with a

[4] J.O.S.A., Nov., 1930.
[5] J.O.S.A., June, 1930, p. 332.

grating or rod screen of the type described, is much more serious. There is a method of some optical interest which I have tested experimentally,

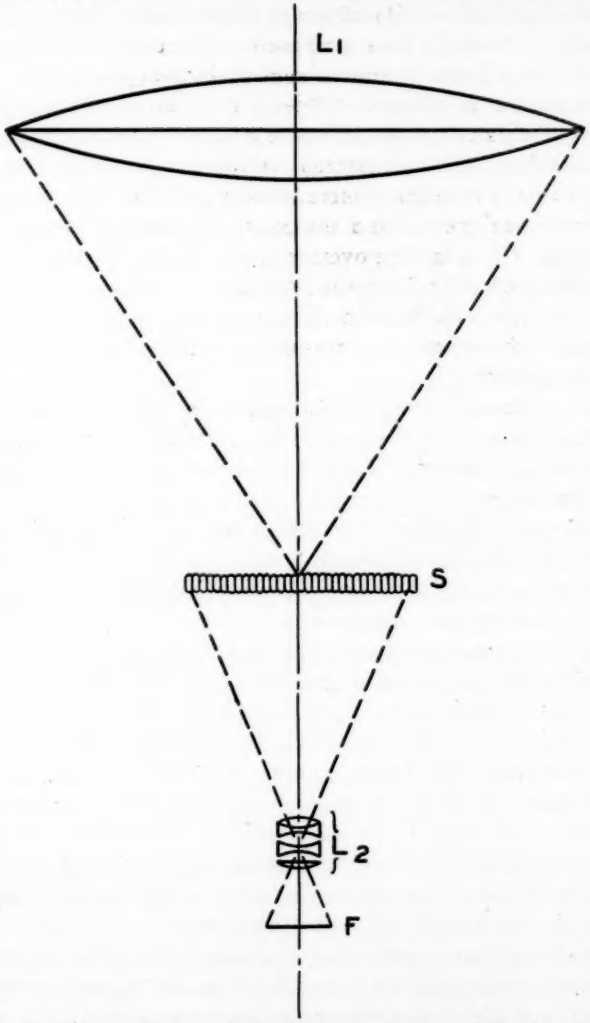

FIG. 4. *Method of making reduced size parallax panoramagram negatives from large diameter lens or mirror.*

involving however a double number of photographic operations with consequent loss of photographic quality. This method consists in mak-

ing a print from the pseudoscopic negative, through a grating placed a short distance behind it, onto a sensitive plate similarly separated from the grating. For a light source for this method of printing, a long line of light is used. The optical arrangement is shown in Fig. 5, in plan and elevation. Considering the center slit of the grating G shown in the plan view, it will be evident that the print from the panoramic strip in the negative N becomes inverted in the shadow picture formed of it on the sensitive plate P. The line of light must obviously be of such length

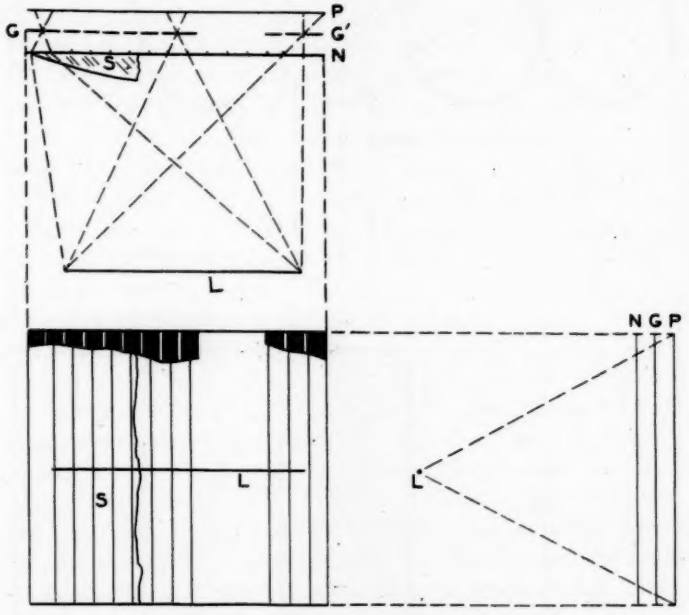

FIG. 5. *Method of copying parallax panoramagrams to invert each strip image.*

as to subtend the angle of the panoramic strip from the grating space. The purpose of using a *line* of light is so that the shadows formed in the direction along the length of the grating lines shall be sharp. Considering next the printing of the panoramic strips lying toward the edges of the negative, it is evident that these would be properly positioned only if, as shown to the right of the diagram, the printing grating G' is of larger spacing than the taking grating, or if a deviating lens of proper curvature is placed against the negative, as is shown to the left of the diagram at S.

Printing by this means, using a grating of slightly larger spacing than the spacing of the panoramic strips, has been tried experimentally with entire success. It has no advantage over the use of the grating behind the print for ordinary parallax panoramagrams; and there is, of course, theoretically, a doubled loss of depth of clear definition due to the printing through a second grating, although this proves to be hardly noticeable in practice. For the present problem, this method does provide a

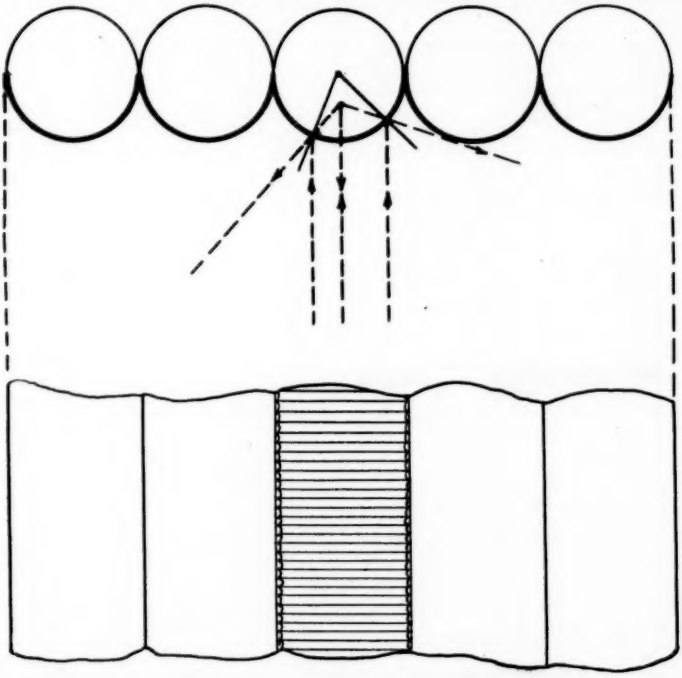

FIG. 6. *Reflecting screen composed of convex cylindrical elements for use with pseudoscopic parallax panoramagrams.*

means of securing a print whose panoramic strips are suitably oriented for projection purposes. The print must, however, now be copied on a reduced scale to be available for projection in the lantern and this must be done in a copying camera in the manner already indicated. This copying operation gives a negative, from which a print is made for projection. Care must be taken in the additional photographic operation not to lose photographic tone quality. The printing operation through

a grating could, of course, be done from a small scale negative obtained directly in the form of camera shown in Fig. 4.

There is, however, another line of attack on the problem of securing the proper orientation of the strip panoramas. Thus far we have considered only the production of *real* images behind a grating, or on the rear surface of a ridged screen. Two procedures may now be described in which the panoramic strip images are *virtual*; these have the advantage for our purpose that the panoramic strips are transposed and are accordingly right way around for proper utilization of the single exposure method of negative making, using a large lens or mirror.

The first method of utilizing virtual images is realized in a reflecting screen, whose rod elements are convex cylindrical surfaces. The general principle is shown in Fig. 6, where one of the cylindrical elements is shown. The element is supposed to have focused upon its face one of the panoramic (pseudoscopic) strips of the negative as obtained with a large lens or mirror. The light incident normally on the axis is reflected straight back to the projection lens. The strip elements falling to either side of the normal are reflected off at increasing angles, depending on their distance from the axis. The reflected rays, when projected back into the cylinder, appear to diverge from a point which is half-way between the axis and the front of the cylinder. This point, which is a virtual image of the projection lens, takes the place of the grating slit in the method of viewing the pseudoscopic panoramagrams with the grating placed behind the picture. In order to see the picture projected on a screen made up of cylindrical elements of this sort, it is necessary to provide for diffusion of the light in the direction parallel to the axes of the cylinders; otherwise merely a point of light, corresponding to the projection lens, will be seen. This is to be done by providing corrugations on the faces of the cylinders, like the threads upon a machine screw, as shown in Fig. 6.

Owing to the laws of reflection, the angle through which the picture is displayed is twice the angle of the circumference on which the strip images fall. A negative, made with an apparatus viewing the object through an angle of 60°, must thus be projected upon strips of these cylinders of only 30° extent. For this reason, complete half cylinders will ordinarily have considerable dead space. This may be obviated by cutting off the sides of the cylinders before they are mounted up together, or dead spaces may be introduced between the strip images in taking the negative, as for instance, by an especially wide spacing of the grating lines, or by using only every other rod of a rod screen.

The second method of utilizing virtual images consists in substituting for the convex cylindrical lenses used in the screen shown in Figs. 1, 2 and 3, a series of *concave* cylindrical lenses. The principle of a translucent screen for projection purposes, using concave elements is shown in Fig. 7a. Images of the parallax panoramagram strips, projected from a distant lens P are brought to a focus at the screen G, each strip in register with a concave element. After emerging from the screen the light

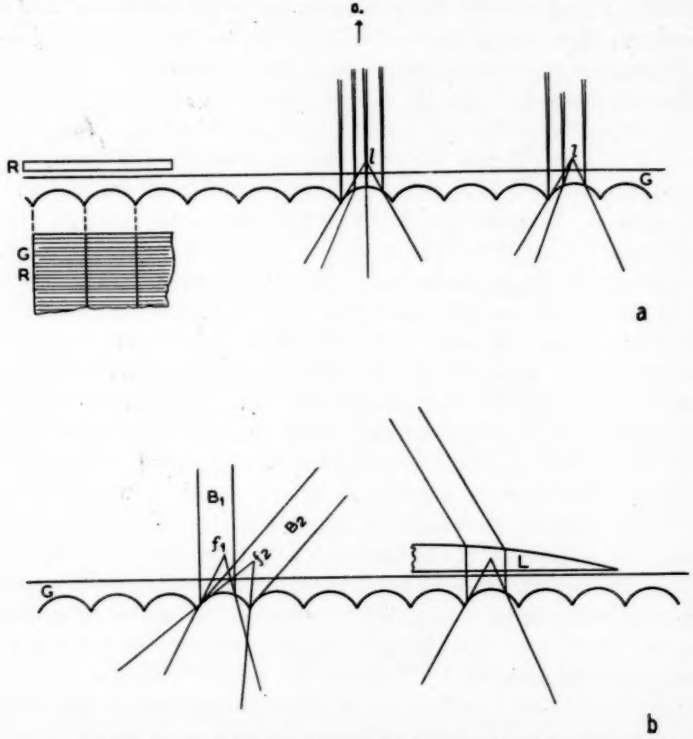

FIG. 7. *Transmission screens composed of concave cylindrical elements.*

rays are divergent, and appear to come from points l, a short distance behind the concave surfaces. These points l, are virtual images of the projection lens, and correspond in action to the clear spaces of a grating. Their brightness depends upon the angle from which they are observed, which in turn is determined by the transmission of a linear element in the panoramic strip projected on the concave element. If however we investigate which linear elements are seen from any particular direction, we find that they are oppositely oriented from those which would be seen if a convex screen structure were used, that is, this screen can use

directly the parallax panoramagrams made with a large lens in conjunction with a grating. One further feature must be provided, namely means for producing diffusion of light in the direction along the ridges, as in the case of the reflecting screen previously described. For this purpose a series of horizontal ridges, such as those on ribbed glass, can be placed behind the screen, as shown at R.

In Fig. 7*b* is shown a method of utilizing the concave element screen for making pictures of any desired size directly in the large lens or mirror camera, in accordance with the principle already discussed and exhibited in Fig. 4. Beams of substantially parallel rays B_1 and B_2, from the large diameter lens, are diverged and emerge from the screen as though emanating from points f_1 and f_2. These points are elements of a virtual panoramic strip apparently located slightly behind the screen. An eye in front of the screen (provided it receives rays from all these virtual points) will perceive a complete parallax panoramagram. A photographic lens, situated as at L_2 in Fig. 4 makes it possible to photograph the image. The strip images so photographed are correctly oriented for viewing through a grating, and hence for projection on the rear of a *convex* rod screen. As in the cases previously discussed, it is necessary here to provide for diffusion of light in the direction along the ridges, which may be done as before by providing horizontal ridges on the back of the screen. It is also necessary to insure that rays from the peripheral ridges fall into the lens L_2, if these ridges are to be shown in the reduced photograph at F. This may be accomplished by placing a large convex lens in contact with the screen, as shown at L. The focal length of this lens will depend on the refractive index of the screen material, and on the distance of the photographic lens L_2; if made short enough it will also take care of the illumination of the ridges along their entire lengths, thus dispensing with the horizontal ribbing.

The advantage of these virtual image screens is that in each case the negative making operation is performed by a single exposure with apparatus involving no moving parts. Theoretically we have here procedures competent for the production of motion pictures in relief, involving no more operations or pieces of apparatus than ordinary motion picture making. Immense practical obstacles are however presented by (1) the small photographic aperture of the narrow strip of the large lens or mirror which is actually effective, necessitating exposures which would probably be impractically long for motion picture purposes; (2) the necessary extreme accuracy of registration of the strip panoramic images on the screen elements, especially difficult with a moving film, and increasingly so the smaller the strips into which the picture is divided.

ON THE THEORY OF PLANE TRANSMISSION GRATINGS

By H. S. Uhler

[Yale University, New Haven, Conn. Received January 12, 1931]

The present paper has two objects the first of which is to develop a pair of theoretical formulae that are independent of the angle of incidence at the ruled surface of plane waves of light, and the second is to investigate the first order terms of the algebraic functions that involve the unavoidable small errors of the settings. The writer has not succeeded in finding the results given below in any of the score of laboratory manuals and theoretical texts on light through which he has searched diligently. To this extent, at least, the results are new.

Let ι denote the angle of incidence reckoned from the normal to the ruled surface. Let β represent the angle of deviation of the diffracted beam of monochromatic light which includes the (extended) normal at the point of incidence. Let β' stand for the angle of deviation which does not contain this normal. β' and β correspond to the same numerical order of diffraction, n, and they are both considered positive. The three angles ι, β, and β' lie in a plane that is perpendicular both to the rulings of the grating and to the edges of the collimator slit.

The assumption, which is usually made tacitly, that the grating has been so ruled and so adjusted as to fulfill rigorously formulae (1) and (2) below for all orders of diffraction (inclusive of the zeroth order) and for all wave-lengths compatible with the grating-space, δ, will be adopted here.

$$n\lambda/2\delta = \sin \tfrac{1}{2}\beta' \cos (\tfrac{1}{2}\beta' + \iota) \tag{1}$$

$$n\lambda/2\delta = \sin \tfrac{1}{2}\beta \cos (\tfrac{1}{2}\beta - \iota). \tag{2}$$

Simplicity may be introduced into the analysis and the final equations may be made to assume forms particularly suitable for logarithmic computation by employing an auxiliary angle ϕ defined by

$$\phi = \iota + (\beta' - \beta)/2. \tag{3}$$

ϕ may be interpreted geometrically as the angle between the (extended) normal to the grating and the line through the point of incidence which lies within the angle β' and makes an angle $(\beta' - \beta)/2$ with the prolongation of the incident ray.

By adding equations (1) and (2), and then eliminating ι by virtue of relation (3) the following formula may be obtained readily.

$$n\lambda/\delta = \cos \phi \sin \tfrac{1}{2}(\beta' + \beta). \tag{4}$$

Equation (4) may be looked upon as a fundamental working formula for the plane transmission grating. Especial emphasis should be laid on the fact that *formula* (4) *is independent of the angle of incidence*, ι. The value zero usually recommended for ι in the laboratory manuals is not contemplated in the derivation of formula (4). Hence this formula does not require either measurement or knowledge of the value of ι.

The next and obvious step is to derive a formula for ϕ in terms of the two directly measured angles β' and β. This may be accomplished without difficulty by forming the difference between equations (1) and (2), and then eliminating ι by aid of relation (3). The resulting equation reduces to form (5).

$$\tan \phi = \sin \tfrac{1}{2}(\beta' - \beta)/(2 \sin \tfrac{1}{2}\beta' \sin \tfrac{1}{2}\beta). \qquad (5)$$

The problem of finding $n\lambda/\delta$ *is completely solved by formulae* (4) *and* (5) *taken together*. ϕ is first calculated by substituting in formula (5) the measured or otherwise known values of β' and β. After this the value of $n\lambda/\delta$ is computed easily from formula (4).

Before taking up the theoretical investigation of errors of setting it may not be superfluous to present the following considerations supplementary to the preceding discussion.

Obviously all possible relative positions of the incident and diffracted beams of light will be covered by taking ι positive or zero, but not negative.

The equation obtained by eliminating $n\lambda/2\delta$ from formulae (1) and (2) may be thrown into the following form.

$$\sin \tfrac{1}{2}(\beta' - \beta)/ \sin \iota = (\sin^2 \tfrac{1}{2}\beta' + \sin^2 \tfrac{1}{2}\beta)/ \cos \iota \cos \tfrac{1}{2}(\beta' + \beta). \qquad (6)$$

Since neither ι nor $(\beta'+\beta)/2$ can become obtuse, equation (6) shows that β' is larger than β ($\iota > 0$). Consequently definition (3) gives $\phi > \iota$ ($\iota > 0$). Incidentally equation (6) virtually involves $\tan \iota$ so that it facilitates the calculation of ι when β' and β are given.

Whenever, in the preceding work, formulae (1) and (2) were combined this was tantamount to making the assumption that these two conditions were valid for the same value of $n\lambda/2\delta$. However since $\beta'+\iota$ can not exceed $\pi/2$, conditions (1) and (2) can be satisfied simultaneously only for values of ι, β', and β which lie respectively within certain ranges. Combining the conditions $\beta'+\iota \gtrless \pi/2$ with formulae (1) and (2), and representing $n\lambda/\delta$ by ρ_0, the following limits are found without difficulty.

$$\sin^{-1}(1-\rho_0) \lesseqgtr \iota \geqq 0,$$
$$2\sin^{-1}(\rho_0/2)^{1/2} \lesseqgtr \beta' \geqq \sin^{-1}\rho_0,$$
$$2\sin^{-1}\left\{(\rho_0/2)^{1/2}[(2-\rho_0)^{1/2}-(1-\rho_0)^{1/2}]\right\} \lesseqgtr \beta \geqq \sin^{-1}\rho_0.$$

It is easy to deduce from formula (2) that β has a minimum of value $2\sin^{-1}(\rho_0/2)$ which occurs when $\beta=2\iota$ or $\beta'=2\phi$.

Attention will be turned now to the second topic of this paper, that is, to the question of the influence on the subsequently calculated value of ρ_0 of errors incurred in making settings upon the boundaries of the angles β' and β. Elimination of ϕ between formulae (4) and (5) leads to the following explicit function of β' and β.

$$\rho_0 = 2\sin\tfrac{1}{2}\beta'\sin\tfrac{1}{2}\beta\sin\tfrac{1}{2}(\beta'+\beta)/[4\sin^2\tfrac{1}{2}\beta'\sin^2\tfrac{1}{2}\beta+\sin^2\tfrac{1}{2}(\beta'-\beta)]^{1/2}. \quad (7)$$

Let ϵ_0, ϵ', and ϵ symbolize the (algebraic) errors affecting respectively the settings made upon the central image ($n=0$), upon the center or axis of the diffraction pattern corresponding to the deviation β', and upon the homologous image at β. Let ρ denote the value of function (7) when β' and β have been replaced respectively by $\beta'+\epsilon'+\epsilon_0$ and $\beta+\epsilon-\epsilon_0$.

On expanding the expression for ρ only as far as the first degree in each of ϵ_0, ϵ', and ϵ and after performing long trigonometric reductions it will be found that,

$$\rho_1 = \rho_0 + \{(a_0b+a')\epsilon + (a_0b-a)\epsilon' - (a+a')\epsilon_0\}/a_0^{3/2} \quad (8)$$

where ρ_1 denotes the algebraic sum of ρ_0 and the first order terms in the series expansion of ρ, and

$$a_0 \equiv (2\sin\tfrac{1}{2}\beta'\sin\tfrac{1}{2}\beta/\cos\phi)^2,$$
$$a' \equiv \sin^2\tfrac{1}{2}\beta'\sin\tfrac{1}{2}(\beta'+\beta)\sin\tfrac{1}{2}(\beta'-\beta),$$
$$a \equiv \sin^2\tfrac{1}{2}\beta\sin\tfrac{1}{2}(\beta'+\beta)\sin\tfrac{1}{2}(\beta'-\beta),$$
$$b \equiv \sin\tfrac{1}{2}\beta'\sin\tfrac{1}{2}\beta\cos\tfrac{1}{2}(\beta'+\beta).$$

The constituent parts of formula (8) might have been obtained in the following alternative manner. Let ξ, η, and ζ denote the angles which are made with the plane of the grating by rays whose deviations have respectively the magnitudes β, 0, and β', so that $\beta=\eta-\xi$ and $\beta'=\zeta-\eta$. Then

$$\partial\rho/\partial\xi = -(a_0b+a')/a_0^{3/2},$$
$$\partial\rho/\partial\eta = (a+a')/a_0^{3/2},$$
$$\partial\rho/\partial\zeta = (a_0b-a)/a_0^{3/2}.$$

Numerical calculations may be checked or facilitated by making use of the interesting fact that here

$$\partial\rho/\partial\xi + \partial\rho/\partial\eta + \partial\rho/\partial\zeta = 0.$$

Let p_1 symbolize the total percent error in ρ due to the discrete errors ϵ_0, ϵ', and ϵ, each expressed in terms of the second (of angle) as unit. Then the first order approximation formula (8) gives

$$\begin{aligned} p_1 &\equiv 100(\rho_1 - \rho_0)/\rho_0 \\ &= \pi\{(a_0b + a')\epsilon + (a_0b - a)\epsilon' - (a + a')\epsilon_0\}/(6480\ \rho_0 a_0^{3/2}) \qquad (9) \\ &\equiv e\epsilon + e'\epsilon' + e_0\epsilon_0. \end{aligned}$$

By fairly long transformations it can be shown that

$$\begin{aligned} a_0b - a = {} & (\sin \tfrac{1}{2}\beta' \cos \tfrac{1}{2}\beta' \cos \tfrac{1}{2}\beta \\ & - \sin^2 \tfrac{1}{2}\beta' \sin \tfrac{1}{2}\beta - \sin \tfrac{1}{2}\beta)[\cos^2 \tfrac{1}{2}(\beta' + \beta) - \cos \beta'] \sin \tfrac{1}{2}\beta. \qquad (10) \end{aligned}$$

By combining the equation $\beta = 2\iota$ with formulae (1) and (2), and eliminating $\rho_0/2$, it will be found that

$$\sin \tfrac{1}{2}\beta' \cos \tfrac{1}{2}\beta' \cos \tfrac{1}{2}\beta - \sin^2 \tfrac{1}{2}\beta' \sin \tfrac{1}{2}\beta - \sin \tfrac{1}{2}\beta = 0. \qquad (11)$$

Expression (11) is identically the first parenthetical factor of (10) hence $a_0b - a$ vanishes when β attains its minimum value. In other words, the error in setting upon the image diffracted at the angle β', corresponding to minimum deviation of β, has no influence upon the calculated value of $n\lambda/\delta$, to the degree of approximation professed. The second (binomial) parenthetical factor of expression (10) is also capable of vanishing. This happens when β' attains its superior limit $2 \sin^{-1}(\rho_0/2)^{1/2}$.

The table given below is based upon the following data. It is assumed that the grating has 10,000 lines per inch so that $\delta = 2.54 \times 10^{-4}$ cm, $\lambda = 5892.8 \times 10^{-8}$ cm, and $n = 2$. Hence $\rho_0 = 464 \times 10^{-3}$. The values of ι were chosen arbitarily and all the remaining tabulated numbers were calculated by using the formulae developed above. From the experimental point of view the first column of the table is superfluous. The numbers in the columns headed e, e', and e_0 may be looked upon as the first approximation component percent errors in ρ when $\epsilon = \epsilon' = \epsilon_0 = 1''$.

The seventh column is based upon the arbitrary values $\epsilon = \pm 20''$, $\epsilon' = \mp 20''$, and $\epsilon_0 = \mp 20''$. The algebraic signs are chosen here so as to produce the arithmetically greatest resultant error in ρ for values of β greater than the minimum $26^\circ\ 49'\ 47''$.

ι	β'	β	$e(1'')^{-1}$	$e'(1'')^{-1}$	$e_0(1'')^{-1}$	$\pm p_1\%$
0°	27°38′44″	27°38′44″	+.000006	+.000006	0	0
5°	28°26′47″	27° 8′18″	+.000676	+.000263	−.000413	.0165
10°	29°37′ 0″	26°52′44″	+.000888	+.000092	−.000796	.0318
13°24′53″	30°41′32″	26°49′47″	+.001016	0	−.001016	.0406
15°	31°17′16″	26°50′24″	+.001073	−.000035	−.001108	.0443
20°	33°42′32″	27° 0′23″	+.001223	−.000111	−.001334	.0533
25°	37°27′ 5″	27°22′18″	+.001320	−.000128	−.001448	.0579
30°	44°34′46″	27°56′13″	+.001342	−.000079	−.001422	.0569
32°24′42″	57°35′18″	28°16′58″	+.001273	0	−.001273	.0509

Attention may be called to the following facts which are illustrated by the table. As proved earlier, $e-e'+e_0\equiv 0$. The range of variation of β as compared with that of β' is small. Each of e and $-e_0$ has a maximum corresponding to a value of ι that is comparatively near the upper limit of this angle. On the other hand, e' behaves in quite a different manner since it passes through zero both at minimum deviation and at grazing diffraction ($\beta'+\iota=\pi/2$). Consequently e' experiences two arithmetical maxima. Leaving out of account data corresponding to extremely small values of ι, the numerical values of e' are very much less than those of e and e_0 which fall in the same (horizontal) row of the table. This fact, combined with the identity $e-e'+e_0\equiv 0$, accounts for the general approximate numerical agreement between the values of e and $-e_0$ which are associated with the same values of ι, β', and β.

In the opinion of the writer, the table and the analysis that established the generality of the behavior of the rate e' indicate that in practice the proposed procedure of ignoring ι and of making settings in the neighborhood of minimum deviation when the grating has been turned into the two azimuths at which minimum deviation occurs for the same order of diffraction, may yield better results,—as a consequence of varying the experimental conditions,—than the procedure recommended in the majority of laboratory manuals, that is, of devoting much time to attempting to adjust the plane of the ruled surface normal to the optic axis of the collimator by the aid of a Gauss eye-piece (or an equivalent). The latter scheme does not give the experimental freedom of the former. Of course, it is presupposed here that no computational difficulty is presented by the use of formulae (4) and (5).

In conclusion emphasis must be laid upon the fact that e, e', and e_0 are angle rates, that is, *first order* partial derivatives with respect to certain angles. Accordingly care must be taken not to misinterpret p_1 if large values are substituted respectively for ϵ, ϵ', and ϵ_0. The second and third order analytical correction terms were found to be too unwieldy

either to admit of interpretation or to merit publication. A numerical illustration must suffice. Consider the effect of e_0 alone ($\epsilon = \epsilon' = 0$) and let $\epsilon_0 = 10' = 600''$. Corresponding in order to the values 0°, 5°, 10°, 15°, 20°, 25°, and 30° for ι, the rigorous values for the respective percent errors in ρ (using Bauschinger and Peters' incomparable logarithmic tables) were found to be 0.0332, 0.278, 0.501, 0.684, 0.812, 0.874, and 0.854%. The last seven numbers should be compared with the results obtained by multiplying the (unabbreviated original) tabulated data for e_0 by 600″, namely, 0.0000, 0.248, 0.477, 0.665, 0.800, 0.869, and 0.853%.

Grundlagen der praktischen Optik. By Dr. M. Berek. VII+152 pages. Published by Walter de Gruyter and Company, Leipzig. 1930.

The author is a member of the scientific staff of E. Leitz and presents a book on geometric optics which embodies the results of long experience in the design of optical systems. Both the trigonometric method of ray tracing and the algebraic method for determining the third order aberrations are satisfactorily presented together with the manner in which the two methods complement each other. Convenient methods are given for indicating graphically the results of trigonometric computation and for showing in tabular form the results obtained by the Seidel equations. The author stresses the importance of determining the contribution of each surface to the aberration in the final image and gives analyses of several typical optical systems. Most of the illustrative examples refer to photographic objectives. The final chapter discusses the photometric relations between the object and image. The book deals only with "geometric optics"; that is, the appraisal of the geometric aberrations in terms of diffraction and the Rayleigh limit is not presented.

I. C. GARDNER

*A NOTE ON THE "SPEED" OF PHOTOGRAPHIC EMULSIONS

By Raymond Davis and Gerald Kent Neeland
[Bureau of Standards, Washington, D.C. Received March 24, 1931]

ABSTRACT

The H & D system of measuring the sensitiveness of photographic materials has been altered in recent years so that different characteristics of the emulsion now have the same name. It is recommended that the procedure in describing emulsion characteristics be clearly indicated.

During the past few years "H. & D." diagrams have shown an increasingly marked variation from those used in Hurter and Driffield's original system for determining the characteristics of photographic emulsions.

Examination of their system,[1] shows that a very definite procedure is indicated. The purpose of the present paper is to point out the necessity of distinguishing deviations from this system. This will help to avoid the present confusion where different "characteristics" of an emulsion are given the same name by different writers.

In this system a curve gives the variation of density with log exposure. Density was definitely specified (see Hurter and Driffield Memorial Volume, p. 329) as being the difference between the total density and the density due to glass, gelatin, and fog on an unexposed part of the same specimen.

The inertia (i) was defined as the exposure value of the intercept on the log exposure axis by the straight line part of this curve extended. The speed of the emulsion was taken as proportional to the reciprocal of this number (the constant of proportionality being 34)[2].

Certain details in the system of sensitometry as it was proposed are admittedly unsuited to present day use. Changes which have been generally made include: 1, Non-intermittent instead of intermittent exposures; 2, A source of light at a color temperature more nearly approaching daylight or sunlight; 3, A different value of the constant of proportionality mentioned in the preceding paragraph.

A variation which several workers have introduced is that of plotting

* Publication Approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] Hurter, F., and Driffield, V. C., *The Hurter and Driffield System*, The Hurter and Driffield Memorial Volume, p. 300.

[2] Ferguson, W. B., Phot. J., *The Hurter and Driffield Method of Speed Determination*, Nov., 1926, p. 514.

total density against log exposure. We wish to point out that speed numbers obtained from curves representing total density plotted against log exposure, differ from those found from curves representing total density minus fog density* plotted against log exposure for, in the latter method, the effect is that of lowering the entire curve by an amount equal to the fog density. Nor will the speed numbers (of two emulsions) obtained by the former method be in the same ratio as speed numbers for the same emulsions obtained by the latter method unless the fog density and slope of the straight line portion of the characteristic curve (gamma) be the same in both cases.**

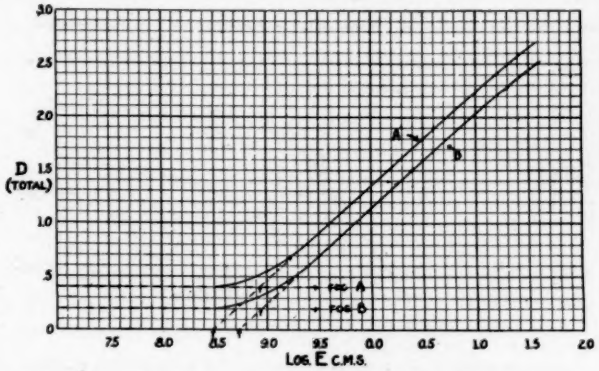

FIG. 1. *Illustrating the case of two negatives giving identical prints and whose speed numbers are identical when obtained by Hurter and Driffield's method and different when obtained on total density basis.*

In the case of curves corrected for fog by some one of the formulas for that purpose the speed numbers obtained would differ from those obtained by either of the preceding methods.

Confusion will be avoided only by adopting a distinctive nomenclature in which new terms are used to indicate the new characteristics, or else Hurter and Driffield's definitions must be specifically modified.

* The term fog density in this case includes that due to fog, gelatin, and support.

** In a paper by Jones and Russell (*The Expression of Plate Speed in Terms of Minimum Useful Gradient*, Proceedings of the Seventh International Congress of Photography, p. 130), speed numbers were given for comparison purposes. Apparently, these were obtained from an "inertia" value which was taken as the intersection of the straight line part of the characteristic curve with the zero density line. Since, in these diagrams, total densities were plotted against log exposure, the "inertias" given differ from those defined by Hurter and Driffield. Hence, as stated, the speed numbers are neither the same as, nor proportional to, speed numbers obtained from curves where total density minus fog density, is plotted against log exposure.

The objection to deriving speed numbers from a total density—log exposure diagram may be seen from a hypothetical (but not at all inconceivable) case. Referring to Fig. 1, which is a total density—log exposure plot, we have two emulsions A and B giving curves such that at each value of log exposure (log E), A gives a total density (D) which is greater than that of B, by a constant amount. In other words, the two curves are of identical shape but one is raised above the other. Consequently, if the values are determined from the intercept on the log E axis the speed number of A will be greater than that of B. However, if they are plotted on a total density minus fog density—log exposure diagram the speed number will obviously be the same for both. That these two emulsions should be considered of the same speed seems only reasonable.

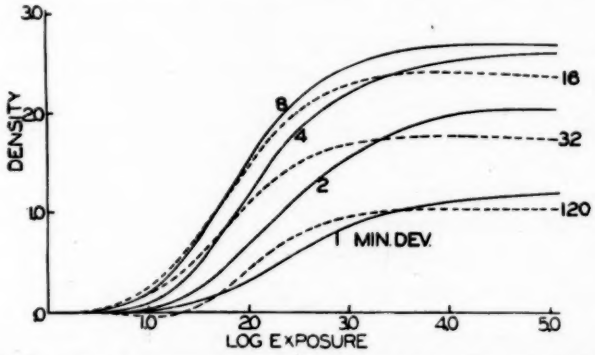

FIG. 2. *Showing a family of characteristic curves for several development times. Density is the difference between total density and fog density.*

The justification for subtracting the fog density from the total density will be seen by reference to Fig. 2, from Prichard,[3] representing a family of characteristic curves. The numbers indicate the time of development in minutes, density means total density minus fog density. (Some of the curves have been dotted in for clearness only). It is to be noted that the contrast first increases to a maximum and then falls off again as the development time is prolonged. While it is, of course, more than improbable that this family of curves represents the action of light alone,* it should be remembered that for purposes of practical sensitom-

[3] Prichard, H. A., *The Fog Correction of Photographic Densities: A Sensitometric Study*, the Phot. J., Nov., 1927, p. 447. (Communication No. 310 from Kodak Research Laboratories.)

* Nietz says (Theory of Development, No. 2 Monographs on the Theory of Photography from the Research Laboratory of the Eastman Kodak Company, p. 141), "From the time of Hurter and Driffield's first investigations, numerous workers have assumed that fog is evenly

etry (i.e., where the results are to be applied to the actual processing of negatives or positives), these curves do represent the contrasts and the effective densities which would be obtained in all negatives or positives made under like conditions.

That this is so, may be shown as follows: In a negative from which a print is to be made one is concerned with total densities; the fractional part of any density due to fog is of no concern. Consider again the case of two emulsions which give under certain conditions (of exposure, development, etc.), total density characteristic curves having identical shape but one lying above the other as in Fig. 1. It is clear that two negatives (one with each emulsion) made under these conditions, would, by proper regulation of the printing exposure, yield identical positives.

Another method of plotting the characteristic curve (somewhat similar to that used by Sheppard[4]) has advantages of both the total density and the total density minus fog density plots. It consists in a total density—log exposure plot with the addition of lines parallel to the exposure axis representing the value of the fog for each curve. Thus the curves are properly spaced. In this plot the intersection of the extension of the straight line portion of the characteristic curve with the fog line will have the same log exposure coordinate as the inertia in the H. & D. plot. Speed numbers obtained in this way will therefore, be identical with those obtained from the Hurter and Driffield procedure. This may be seen from consideration of Fig. 1.

In the foregoing discussion it has been assumed that the emulsions considered were such as to give curves, parts of which were approximately straight. It is well known that the curves for some emulsions do not in any part approximate a straight line. In such cases specification of speed by Hurter and Driffield's system is manifestly impossible.

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distributed over the image and have accordingly subtracted the fog readings from the density values for sensitometric strips. More recently several workers have investigated this procedure and one or two have suggested what may now be proved, that fog (over the image) decreases as the image density increases."

Underlying the foregoing is the idea that what is wanted is, necessarily, the density (upon development) due alone to light, separated from that due to the processing. Whether or not this is desirable depends upon the purpose for which the sensitometric investigation is made.

It is not intended to attempt to minimize the value of the fog correction formulas to the investigator. For studying certain properties of the photographic emulsion, they are undoubtedly a step in advance. However, it is important to make clear the system used and to avoid the comparison of results obtained from different procedures.

[4] *The effect of Concentration of Sensitizer on Speed with a Note on Fog Corrections*, Sheppard S. E., *Phot. Journ.*, Aug., 1926, p. 399.

NOMENCLATURE AND STANDARDS FOR BIOLOGICALLY-EFFECTIVE RADIATION

By M. Luckiesh and L. L. Holladay

[Lighting Research Laboratory, General Electric Company, Nela Park, Cleveland. Received March 26, 1931]

The biological effectiveness of ultraviolet radiation has been widely studied and utilized, but the important foundation of physical science and logical terminology is still almost entirely lacking. With the increasing use of ultraviolet radiation and the promise of general applications of artificial sunlight[1] in dual-purpose lighting, nomenclature and standards are much needed. The output of ultraviolet radiation between certain wave-length limits may be determined for any source in terms of available units of energy or power. However, the measurement of biological efficiency by a physical method requires weighting the radiant energy of each wave length with its corresponding biological effectiveness.

From the viewpoint of physics the procedure is quite simple, but spectral data pertaining to the biological effectiveness of ultraviolet radiation are almost entirely lacking. This absence of spectral data emphasizes the need for physical standards and units and for simplified terminology which properly relate physical measurements with biological effectiveness. Obviously, it is impossible to complete a system of nomenclature and standards without having available the necessary spectral data from the biological realm. However, little progress can be made out of the present chaos without having available at least these objectives, theoretical as they may be for a while. Therefore, the present paper aims to suggest some of the necessary new terminology and to construct the analogy between radiation in the production of luminous effect and of biological effect.

The process of evolution of terminology for light and lighting has given birth to some terms which may not be necessary at present or at least may not be as logical as could be desired in the present stage of advancement of the science and art of lighting. In basing the present discussion upon the analogy mentioned, there is danger of extending some of the undesirable features of nomenclature and standards into a new field. On the other hand, the extensive and recent experience in connection with light and lighting is particularly valuable in clarifying the objectives pertaining to radiant energy and biological effect. The

[1] Artificial Sunlight, by M. Luckiesh, D. Van Nostrand Company, New York, 1930.

suggestions in this paper make no bid for completeness or finality. They are merely an initial attempt to dissipate some of the present confusion and unwieldiness of necessarily complex phrases.

The lumen is the unit of luminous flux and it is defined as the luminous flux emitted in a unit solid angle (a steradian) from a uniform point-source of one candle. Similarly, we might define the unit of biologically-effective flux emitted in a unit solid angle from an imaginary uniform point-source of biologically-effective radiation. We may term this analogue of the lumen a *viton* or something else.

A few salient characteristics of such a unit are presented in Table 1.

TABLE 1

	Pertaining to visible radiation	*Pertaining to ultraviolet radiation* (Analogous)
Unit	Lumen	Viton (for example)
Quantity	Luminous flux	Biologically-effective flux
Combining	a. Spectral sensitivity of the eye *and* b. Spectral distribution of visible radiation	a. Spectral biological effectiveness *and* b. Spectral distribution of ultraviolet radiation
Result	Spectral distribution of luminosity (Integrated = lumens)	Spectral distribution of a specific biological effectiveness (Integrated = vitons)

There are many biological effects of radiant energy, but spectral data pertaining to most of them are almost entirely lacking. It is likely that the "spectral curves" of effectiveness differ markedly. In fact, there is no reason to expect that any two of them are identical. Some of these biological effects of ultraviolet radiation which are of great interest to the health of human beings at the present time seem to be confined to radiant energy shorter than λ3200 or even λ3100. In order to provide reasonable safety to the eyes, the energy shorter than λ2800 may be arbitrarily eliminated by filters, although, of course, fundamental units must take into account the spectral ranges which are utilized. The long-wave limits of biological effectiveness of ultraviolet radiation are known approximately for germicidal, erythemal and antirachitic effects. The short-wave limits are even less defined. The spectral effectiveness of radiation in the production of erythema (minimum perceptible) upon average untanned human skin is now fairly well established.[2] For this

[2] *Reaction of untanned human skin to ultraviolet radiation*, by Luckiesh, Holladay and Taylor, J.O.S.A., *20*, 423; 1930.

reason this biological effect has been chosen for the purpose of illustration. The production of erythema is a common by-product of ultraviolet radiation, but it is not essential in order to receive some of the known benefits of ultraviolet radiation. One of the authors[1] has employed minimum perceptible erythema merely as one means of measuring ultraviolet radiation of wave lengths known to be beneficial to the health of human beings.

In Fig. 1 a few "spectral curves" are shown. With the exception of the spectral erythemal curve these may be considered to be approximations used to illustrate that "variable units" may be necessary eventually in order to be applicable to a variety of biological effects.

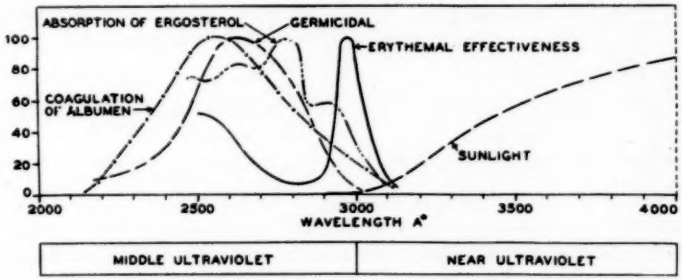

FIG. 1. *Approximate relative biological effectiveness of radiation of various wave lengths for certain known "photochemical" activities. The spectral distribution of solar radiation is also shown.*

In Fig. 2 is provided a view of the analogy of actions of visible radiation upon the receiving visual sense and of ultraviolet radiation upon the receiving skin. The result in one case is luminosity; in the other, erythema. *A* shows the spectral distribution of energy from a 1-watt blackbody at 6000°K which radiates uniformly in all directions. *B* is the *visibility curve* of radiation or the spectral sensitivity of the visual organ. When visible radiation is properly weighted throughout the proper spectral range by applying the factors in *B* to the corresponding factors in *A*, the spectral luminosity curve *C* is obtained. The area under *C* is proportional to luminous flux.

Similarly, *D* is the *erythemal curve* of radiation or the spectral sensitivity of the skin in the development of erythema. An *antirachitic curve* might have been chosen if it were available. *E* represents the specific biological (erythema-producing) effectiveness of ultraviolet radiation produced by applying the factors in *D* to the corresponding factors in *A*. The area under *E* is proportional to the erythema-producing flux. If we

had chosen the *antirachitic curve* for D, the area under E would have been proportional to the *antirachitic flux*.

If this 1-watt black-body at 6000°K were adopted as a unit source of biologically-effective ultraviolet radiation, it would emit 4π *vitons;* and each viton of erythema-producing flux would correspond to 0.9 milliwatt of weighted integral power. That is, the mechanical equivalent of a *viton of erythema-producing radiation* would be 0.0009 watt. This value would in general differ for another biological effect.

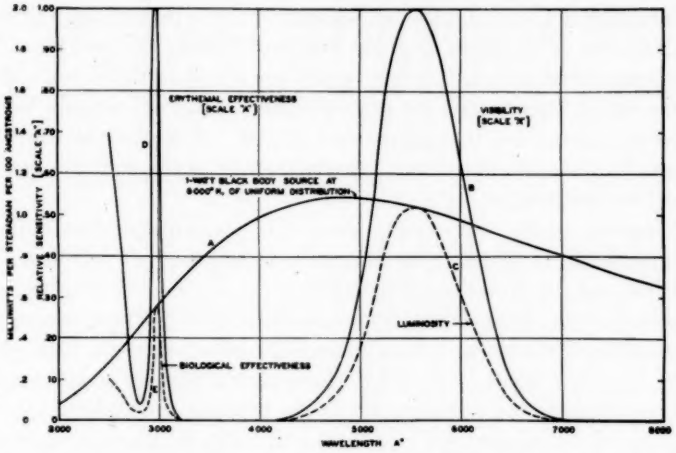

FIG. 2. *A. Spectral distribution of radiation from a 1-watt black body at 6000°K radiating uniformly as a point source.*

B. Visibility curve of radiation.

C. Luminosity curve.

D. Relative effectiveness of radiation of various wave lengths in producing minimum perceptible erythema; that is, the erythemal curve of radiation.

E. Spectral erythemal effectiveness of the radiation from the 1-watt black-body at 6000°K.

The mechanical equivalents of the *viton* for the spectral biological effects illustrated in Figs. 1 and 2 are approximately as follows:

Erythemal viton	0.9	milliwatts
Germicidal viton	1.5	"
Albumin-coagulating viton	1.8	"

The weighted light-producing power per steradian from the 1-watt black-body at 6000°K is the area under C in Fig. 2 and is equal to 10.9 milliwatts. Assuming the mechanical equivalent of light to be 1.61

milliwatts per lumen,[3] the luminous intensity of this source is 6.75 lumens per steradian.

A theoretical standard source which emits a unit of biologically-effective ultraviolet flux per steradian, or a total of 4π vitons, might be termed a *radion*. If we confine our considerations to the application of ultraviolet radiation, the theoretical standard source might be termed a *uvion*. However, the term radion would be applicable to any biological effect of radiation, such as the use of short-wave infrared in "deep therapy" for human beings or of visible radiation in the development of chlorophyll in plants. Of course, we might turn to mythology and adopt such a term as *Hyperion* after the father of Helios. As a matter of fact, this theoretical standard source would provide a scientific foundation-stone rather than a unit for practical use. Therefore, a name for it is more of a theoretical than a practical necessity. For example, the candle as a unit of luminous intensity has relatively little practical use since the advent of the lumen.

From the analogy between visible and biologically-effective radiation a name might be given to the unit of biological flux per unit area. This unit intensity of illumination with biological flux would be analogous to the footcandle. A strict analogy would result in a viton per square foot. The utility of such a unit is obvious and a short name for it would be very desirable. There is no need for carrying the analogy as far as a foot-radion, a foot-uvion, or a foot-hyperion. It seems desirable to take advantage of the opportunity available and adopt such a name as *Finsen* in honor of a recognized pioneer in the biological use of radiation.

The unit for diffusely reflected or transmitted biologically-effective radiation would be a viton per unit area. At the present time it seems unlikely that a term analogous to brightness would be of much use.

The luminous efficiency of a source of radiation is expressed in lumens per watt. Similarly the efficiency of a source as measured by a specific biological effectiveness would be expressed in vitons per watt. Of course, as previously stated, the viton would be a specific one applying to the particular biological effect.

The lumen-hour has little application outside the realm of cost of lighting. However, in applications of biologically-active radiation, time or duration of exposure is an important part of dosage. In fact, the viton-hour would be analogous to milligrams of cod-liver oil, for example.

We have proposed the *finsen* as an analogue of the footcandle. There-

[3] The luminous properties of the black-body, by H. E. Ives, J.O.S.A., *12*, 75; 1926.

TABLE 2. *Summary of analogous units and names employed in defining visible radiation and possible ones for use in defining biologically-effective Ultraviolet radiation.*

Character of unit	*Pertaining to visible radiation*		*Pertainiug to ultraviolet radiation*	
	Unit	*Name of unit*	*Unit*	*Name of unit*
Source intensity	Candlepower	Candle	1-watt black-body at 6000°K	Radion
Flux per unit solid angle from a uniform source of unit intensity	Luminous flux per steradian	Lumen	Vito-flux per steradian	Viton
Intensity of flux	Lumen per square foot	Footcandle	Viton per square foot	Finsen
Exposure	Lumen *x* time	Lumen-hour	Viton *x* time	Viton-hour
Intensity of exposure	Footcandle *x* time	Footcandle-hour	Foot-radion *x* time	Finsen-hour
Efficiency of source	Luminous efficiency	Lumens per watt	Biological efficiency	Vitons per watt
Diffuse reflection	Emission of one lumen per square foot	Foot-lambert	Emission of one viton per square foot	.....
Watts equivalent of radiation of wave length of maximum effectiveness	Mechanical equivalent of one lumen	.00161 watts per lumen	Mechanical equivalent of one viton	Depends upon the specific viton

fore, finsen-hours would be analogous to footcandle-hours. In order to utilize a finsen-hour as a measure of dosage it must be multiplied by area of exposed surface. Finsen-hours times area of the receiving surface in square feet yields viton-hours.

The units and terms discussed in the foregoing paragraphs are presented in Table 2, bearing in mind the basic analogy which has been followed. In considering these we are confronted with a conflict between the prevalent use of the foot as a linear unit in lighting practice in this country and the scientific advantage of the metric system. Notwithstanding the latter, it appeared necessary in this preliminary discussion to adhere closely to the established usage. However, the suggestions may be readily converted into the metric system to satisfy scientific usage in this country and almost universal usage elsewhere.

It is evident that it would be convenient to have a prefix, such as vito-, which could be used with such words as watts, energy, power, efficiency, effectiveness, etc. This prefix would signify that the biologically-active radiation has been properly weighted according to its relative spectral effectiveness for the specific biological effect considered. Then we could speak of vito-energy, vito-efficiency, etc.

In closing this brief summary of a complex subject which is in urgent need of units and terms, it is of interest to consider briefly the magnitude of the unit of vito-flux, tentatively termed the viton.

For consideration of the magnitude of the viton, the order of magnitudes of weighted erythema-producing watts per steradian is presented in Table 3 for several commercial and theoretical sources. Little is known regarding the spectral antirachitic effectiveness of radiation, but it appears that the maximum is near the wave length of maximum erythemal effectiveness and at least the long-wave limits of effectiveness of radiation are approximately the same for the two cases. Therefore, an antirachitic viton would be of the same order of magnitude as the erythemal viton.

TABLE 3. *Order of magnitude of the weighted erythema-producing watts per steradian supplied by various sources.*

60-watt MAZDA CX with Corex D bulb; filament at 2820°K	0.00009
500-watt MAZDA CX with Corex D bulb; filament at 3035°K	.0016
Sunlight MAZDA lamp (S-1) with Corex D bulb	.02
Quartz mercury arc	.3
1-watt black-body at 6000°K	.0009
1-candlepower black-body at 6000°K	.00013

Radiation from zenith sun through one clear atmosphere supplies about 0.01 weighted erythema-producing watts per square foot of horizontal surface.

In Table 3 it is seen that the weighted amounts of erythema-producing radiation per steradian from these commercial sources varies from 0.00009 to 0.3 watt. The values for 1-watt and 1-candlepower black-bodies at 6000°K are, respectively, 0.0009 and 0.00013 watt.

If a 1-watt black-body at 6000°K were chosen as a standard source of biologically-active radiation (one radion emitting 4π vitons), the 500-watt MAZDA CX lamp with Corex D bulb and filament at 3035°K would seem to be a practical standard source. It would supply nearly 2 erythemal vitons per steradian and probably about the same number of antirachitic vitons. On this same basis the best sunlight would supply about 10 vitons per square foot upon the earth's surface.

If a uniform 1-candlepower black-body source at 6000°K were adopted as a radion, it would possess certain advantages. From each solid angle would be emitted a unit of vito-flux (viton) and a unit of visible flux (lumen). It has a fairly uniform spectral distribution of energy in the visible region (Fig. 2) and it emits practically a white light and has a relatively large component of ultraviolet energy. On this basis the 500-watt MAZDA CX lamp would be a practical standard emitting about 10 vitons of the kind under discussion.

Another alternative would be to standardize the weighted integral value of biologically-effective radiation per steradian as 0.1 or 1 milliwatt; or, in other words, to standardize the mechanical equivalent of a viton as 0.1 or 1 milliwatt. In this case the mechanical equivalent of a viton of erythema-producing radiation would be equal to a viton of germicidal radiation or a viton of antirachitic radiation.

The unit of exposure, such as the viton-hour, should in any event be based upon a biological effect readily used and measured.

MINUTES OF THE EXECUTIVE COUNCIL

Meeting at New York, N. Y., February 25, 1931

Besides the transaction of routine business, the following items of general interest to members of the Society were taken up.

1. *1931 Election.* Arrangements for the 1931 Election were completed (as announced in this issue of the Journal of the Optical Society of America, page 429).

2. Invitations for February Meeting. Invitations were presented from Karl T. Compton, President of Massachusetts Institute of Technology, and from Theodore Lyman, Director of the Jefferson Physical Laboratory, inviting the Optical Society of America to hold a Joint Meeting with the American Physical Society in Cambridge, February 1932 as a part of a celebration of the opening of the new physics laboratory at the Massachusetts Institute of Technology, and the extension of the Jefferson Physical Laboratory.

The Council voted to accept the invitations.

3. *Appointment of Editor-in-Chief.* Dr. Paul D. Foote was reappointed Editor-in-Chief of the Journal for the term January 1, 1932 to December 31, 1936 with the understanding that the Council will accept his resignation during 1932 if it seems to him desirable.

4. *Frederic Ives Medal.* It was decided that the Frederic Ives Medal be awarded at the Annual Meeting and a committee on the award was appointed by the President.

L. B. TUCKERMAN, *Secretary.*

OPTICAL SOCIETY OF AMERICA

Notice of Election of Officers

In accordance with the by-laws, an election will be held in October to elect the following officers:

For the term January 1, 1932 to December 31, 1933

President
Vice-President

Four members of the Executive Council

For the term January 1, 1932 to December 31, 1936

Treasurer

The following Committee on Nominations has been appointed and confirmed in accordance with Article IV, Section 3 of the by-laws:

I. G. Priest, Chairman
Bureau of Standards,
Washington, D. C.

Adelbert Ames, Jr.,
Dartmouth College,
Hanover, N. H.

J. A. Anderson,
Mt. Wilson Observatory,
Pasadena, Calif.

A. H. Pfund,
Johns Hopkins University,
Baltimore, Md.

W. B. Rayton,
Bausch and Lomb Optical Co.,
Rochester, N. Y.

It will be the duty of this Committee to make nominations for the above mentioned election. The Committee's report is to be made not later than August 25, 1931.

So far as the by-laws are concerned the Committee has full power to decide whom it will nominate, but members of the society are urged to suggest names which they think should be considered by the Committee. Suggestions may be sent to the Chairman or any other member of the Committee.

Only regular and honorary members are eligible to election.

P. E. Klopsteg, having served two consecutive terms, is not eligible for re-election as member at large of the Executive Council.

The following tellers have been appointed to canvass the ballots:

James E. Ives, Chairman
Francis P. Phelps
Arthur Q. Tool.

(Signed) L. B. Tuckerman,
Secretary.

NEW YORK MEETING OF THE OPTICAL SOCIETY OF AMERICA

February 26–28, 1931

Joint Meeting with the American Physical Society

A joint meeting of the Optical Society of America and the American Physical Society was held in New York, February 26th to 28th, 1931.

The sessions on Thursday under the auspices of the Optical Society of America were held at the Museum of Science and Industry. The meetings on Friday and Saturday were held at Columbia University.

Notable features of this meeting were: (1) The sessions of the Optical Society of America on Thursday and Friday mornings devoted to "Consideration of Color Problems." In connection with it opportunity was offered members to visit the interesting color exhibitions at the Museum. (2) The meeting on Thursday evening of delegates of organizations invited to participate in a preliminary conference on organization of an "Inter-Society Committee on Color." (3) The joint session with the American Physical Society on Friday afternoon at McMillin Theatre. (4) A joint dinner of the American Physical Society and the Optical Society of America on Thursday evening followed by a special program on Color at the Museum of Science and Industry.

AT THE SPECIAL SESSIONS ON "COLOR PROBLEMS" THE FOLLOWING INVITED PAPERS WERE PRESENTED:

Thursday Morning at 10 o'clock
Museum of Science and Industry

INVITED PAPERS ON

INDUSTRIAL COLOR STANDARDS

G. F. A. Stutz **Fundamental Research Division, New Jersey Zinc Company**
REFLECTANCE MEASUREMENTS IN THE PAINT INDUSTRY

Carl Z. Draves **Technical Laboratory, E. I. du Pont de Nemours and Company**
SPECTROPHOTOMETRIC MEASUREMENTS IN THE DYESTUFFS INDUSTRY

W. B. Van Arsdel **Research Department, The Brown Company**
COLOR SPECIFICATION IN THE PULP AND PAPER INDUSTRY

W. D. Appel **Bureau of Standards**
COLOR PROBLEMS IN THE TEXTILE INDUSTRY

A. E. O. Munsell **Munsell Research Laboratory**
THE MUNSELL BOOK OF COLOR

M. Rea Paul, Research Laboratories **National Lead Company**
THE DICTIONARY OF COLOR

Margaret H. Rorke Textile Color Card Association of the United States, Inc.
THE WORK OF THE TEXTILE COLOR CARD ASSOCIATION

Thursday Afternoon at 2 o'clock
Museum of Science and Industry

INVITED PAPERS ON

SPECTROPHOTOMETRY AND THE USE OF PHOTOELECTRIC METHODS IN COLORIMETRY

Herbert E. Ives and E. F. Kingsbury — **Bell Telephone Laboratories**
THE APPLICABILITY OF PHOTOELECTRIC CELLS TO COLORIMETRY

K. S. Gibson — **Bureau of Standards**
SPECTROPHOTOMETRY AT THE BUREAU OF STANDARDS

Paul McMichael and Monroe Barnard — **American Photoelectric Corp.**
SOME COMPARATIVE SPECTROPHOTOMETRIC MEASUREMENTS

P. J. Mulder and Joseph Razek — **University of Pennsylvania**
THE RAZEK-MULDER COLOR ANALYZER: PART I. GENERAL DESCRIPTION INCLUDING RECENT IMPROVEMENTS. PETER J. MULDER, PART II. DISCUSSION AND EVALUATION OF ERRORS IN THE INSTRUMENT, JOSEPH RAZEK

Irwin G. Priest — **Bureau of Standards**
SOME REMARKS ON CURRENT PROPOSALS RELATIVE TO THE APPLICATION OF VARIOUS PHOTOELECTRIC INSTRUMENTS TO PRACTICAL PROBLEMS OF COLOR SPECIFICATION

Friday Morning at 10 o'clock
Columbia University

INVITED PAPERS ON
COLOR SPECIFICATIONS

Irwin G. Priest — **Bureau of Standards**
FUNDAMENTAL PRINCIPLES OF COLOR SPECIFICATION

Deane B. Judd — **Bureau of Standards**
CHROMATIC SENSIBILITY TO STIMULUS DIFFERENCES, AND TOLERANCES IN COLOR SPECIFICATIONS

AT THE JOINT SESSION ON FRIDAY THE FOLLOWING INVITED PAPERS WERE PRESENTED:

Friday Afternoon, 2:30 o'clock
McMillin Theatre, Columbia University

INVITED PAPERS ON

PHYSICAL PROBLEMS RELATED TO THE BIOLOGICAL EFFECTS OF RADIANT ENERGY

Brian O'Brien — **Institute of Applied Optics, University of Rochester**
SOME PHYSIOLOGICAL EFFECTS OF LIGHT

Harvey B. Lemon — **The University of Chicago**
THE SPECTRA AND ANTI-RACHITIC POTENCY OF VARIOUS "THERAPEUTIC" LAMPS

Harold W. Webb — **Columbia University**
METHODS OF MEASURING RADIANT ENERGY

SIMULTANEOUS SESSIONS OF THE AMERICAN PHYSICAL SOCIETY WERE HELD ON FRIDAY MORNING, SATURDAY MORNING, AND SATURDAY AFTERNOON.

PROGRAM OF SESSIONS FOR CONTRIBUTED PAPERS

(TITLES AND ABSTRACTS OF PAPERS)

The abstracts were preprinted in the program subject to correction by the authors. Corrections that have been communicated to the secretary have been made in the abstracts reprinted below.

Friday Morning at 11 o'clock
Columbia University

CONTRIBUTED PAPERS

H. P. Gage — **Corning Glass Works**

COLORIMETRIC EFFICIENCY OF RED GLASS

With the advent of colorimetric specifications for colored signal glasses such specifications have been promulgated as "red glass transmitting 40 percent of the incident light" and "red glass transmitting 9 percent of the incident light and having a dominant hue of .640μ."

Assume a red glass transmitting 100 percent for all wave lengths greater than the cut-off point and zero for all wave lengths shorter, the luminous transmission would be the sum of all terms in a luminosity curve for wave lengths greater than the cut-off point, divided by the sum of all terms. The luminosity curve must be for the light source used, as for example Acetylene at 2360°K, and preferably one in which the sum of the terms is 1.00. The trilinear coordinates of the same light source are determined when all wave lengths less than the cut-off point are absent and all wave lengths greater are present with full intensity. Curves are drawn for cut-off point as abscissae against luminous transmission and against percent red and against dominant wave length. The theoretical transmission of a perfect red glass of given dominant wave length can then be compared with that found by spectrophotometric analysis of an actual red glass.

Bibliography:

Report on Colorimetry, J.O.S.A. & R.S.I., 6, p. 527, Aug. 1922.

J. F. Skogland, Miscellaneous Publications, Bureau of Standards (No. 86) tables, p. 19.

H. P. Gage, Practical Considerations in the Selection of Standards for Signal Glass in the United States, Proceedings ICI, Table p. 856.

Dorothy Nickerson — **Bureau of Agricultural Economics, U. S. Department of Agriculture**

A COLORIMETER FOR USE WITH DISC MIXTURE

The colorimeter to be described is one developed with the cooperation of Mr. Carl W. Keuffel. It measures either a large or a small area and integrates the color of a surface even though it may be highly variegated.

The method of measurement, by the use of disc mixture of Munsell papers, permits the expression of results in terms which adequately approximate the psychological attributes: hue brilliance and chroma (or saturation). If it seems preferable, measurements may be made through color filters to give tri-chromatic data, or the colorimeter may be transformed into a simple analyser by the use of filters transmitting a narrow band of wave lengths. In such cases, black and white discs of known reflection are used to make the photometric match.

Dorothy Nickerson **Bureau of Agricultural Economics**
U. S. Department of Agriculture

COLOR MEASUREMENTS IN PSYCHOLOGICAL TERMS

With the colorimeter previously described and with one somewhat similar, measurements have been made on thousands of samples of agricultural products. Many of them were made with a view either to establishing standards for the grade factors of color or to calibrating the color in existing standards. Data will be given to illustrate how this method answers the purpose. Data will also be presented regarding the precision with which such measurements are made.

Saturday Morning, 10 o'clock
Columbia University

Selig Hecht **Columbia University**

INTERRELATIONS AMONG VARIOUS ASPECTS OF COLOR VISION

The data of color vision which include measurements of the luminosity of the spectrum, color mixture, least perceptible colorimetric purity, hue discrimination, and relative luminosities of spectral complementaries, have each been secured on different eyes. Therefore theoretical comparisons among the data cannot be rigorously exact. However, one can construct theoretical mechanisms (a) that yield all the visual functions in approximate agreement with data; or (b) that yield some functions in perfect agreement, and the rest in approximate agreement with data. Since all visual functions are interrelated, the choice of function for approximate or precise derivation is arbitrary.

In terms of certain ideas three cone primaries were suggested, whose spectral distributions were planned to yield an exact agreement with measurements of hue discrimination, least perceptible colorimetric purity, and the luminosity of the spectrum. They gave the relative luminosities of spectral complementary colors in close approximation to data. However, they were made to agree only very roughly with standard color mixture data, because the importance of these data seemed exaggerated.

To show that the ideas involved are unaffected by such very rough agreement, several sets of cone primaries have been prepared. One set yield exactly the O.S.A. excitations, and a normal visibility curve; a hue discrimination function which shows the same form, and the same location of maxima and minima as the data; a minimum perceptible colorimetric purity function of the same form as the data, though differing in detail; and the relative luminosities of spectral complementaries essentially as before.

Another set of cone primaries furnish an exact agreement with the hue discrimination data, and a normal visibility curve; color mixture curves which, though not exactly corresponding to the O.S.A. curves, agree with them to the extent shown by the individual measurements which formed the basis of the O.S.A. curves; and an adequate description of spectral complementary luminosities.

Other cone primaries have been prepared which do similar things. Their preparation and adequacy is determined largely by time and patience. The ideas involved remain the same and may be tested by determining the different visual functions on the same eye.

The present paper will appear in full in J.O.S.A.

Deane B. Judd **Bureau of Standards**

COMPARISON OF DISTRIBUTION CURVES EMBODYING WRIGHT'S RECENT RESULTS WITH THE O.S.A. "EXCITATION" CURVES

Wright[1] has recently reported for 10 observers the trilinear coordinates of the spectrum referred to the colors corresponding to 460, 530, and 650 mμ, respectively, as primaries, and to the N. P. L. standard white as basic stimulus. Furthermore these results are so adjusted as to refer to the average macular pigmentation of 36 normal observers. Since the final average is

much more securely founded than the average embodied in the O.S.A. "excitation" curves which have been in provisional use for nearly 10 years, it is of interest to compare the two sets of curves. Accordingly, distribution curves have been derived which embody Wright's results and which embody the same visibility function as the O.S.A. "excitation" curves. Furthermore, since these curves give the distributions of the primary colors of the O.S.A. "excitation" curves throughout the spectrum of Abbot-Priest sunlight and have the same areas, they are directly comparable with the O.S.A. "excitation" curves referred to Abbot-Priest sunlight as prime-basic stimulus.

A comparison of these two sets of curves reveals a degree of correspondence which is rather surprising in view of the somewhat insecure foundation of the O.S.A. "excitation" curves. The discrepancies which do appear would be considerably decreased if the "eye" specified by the O.S.A. "excitation" curves were changed to refer to observation through a yellow filter about half as dense as that found by Sachs[2] to be the equivalent of the average human macula lutea. This change in pigmentation is well within the limits of normal variation.

It is concluded that there is little urge to supplant the O.S.A. "excitation" curves for colorimetric computation on the ground that they do not represent with sufficient accuracy average normal vision; the gain in accuracy to be obtained by substitution of a set of distribution curves embodying Wright's results is of too little practical importance to compensate adequately for the inconvenience of changing from one standard set of curves to another.

Bibliography:

[1] W. D. Wright, A Re-Determination of the Trichromatic Coefficients of the Spectral Colours, Trans. Opt. Soc *30*, pp. 141–164; 1928–29.

[2] M. Sachs, Ueber die specifische Lichtabsorption des gelben Fleckes der Netzhaut, Pflüger's Arch., *50*, pp. 574–586; 1891.

At the request of the National Illumination Committee of Great Britain, Mr. Priest communicated, in discussion of the above paper, a part of a memorandum by J. Guild entitled "A Normal Eye for Colorimetry" (Document "15 Great Britain 3," International Commission on Illumination).

The introductory part of the document is as follows:

> "It appears desirable that early attention should be given to the standardising of a set of colorimetric data for the spectrum, to represent the properties of a "normal" eye for colorimetric purposes in the same way as the I. C. I. standard visibility curve represents a "normal" eye for photometric purposes.
>
> This has not appeared to be practicable until quite recently, owing to the small amount of available data of a sufficiently reliable character.
>
> In 1922 the Colorimetry Committee of the American Optical Society recommended a set of data computed by Weaver from the results of König and Abney as being the best available at that time. Our experience at the National Physical Laboratory showed that this data was inadequate for many purposes. This is by no means surprising when the meagerness of the original data, and the approximate assumptions that have to be made in reducing them to a common basis are taken into account.
>
> Four years ago measurements were carried out on seven observers at the National Physical Laboratory. This was intended to be part of a much larger investigation, but the exigencies of other work prevented extension to a larger group at that time, and it has not yet been possible to resume it. A set of spectral mixture curves was prepared by combining the trichromatic coefficients of these seven observers with the I. C. I. visibility curve.
>
> This data was found to meet our requirements very satisfactorily and has been used for a variety of purposes, including the preparation of the list of comparative values for signal glasses given in the appendix to the Report of the Secretariat Committee on signal glasses presented at the 1928 meeting of the I. C. I. Results calculated from the data were in close agreement with direct colorimetric measurements made by "ordinary" observers. Never-

theless, although our tests showed this data to be much more nearly representative of "ordinary" vision than Weaver's data, the number of observers was too small to justify putting forward their results as an adequate basis for a provisional standard, and publication was postponed in the expectation that the work could be resumed at an earlier date than has proved to be possible.

Meanwhile W. D. Wright has published the results of measurements carried out on ten observers at the Imperial College of Science. The colorimetric data given by Wright, as embodied in his trichromatic coefficients, agree so surprisingly closely with those obtained for the seven-observers group at the National Physical Laboratory, as to suggest that both groups give a close approximation to normal vision, and that the two sets of results provide a satisfactory basis for a provisional standard."

In this connection, Mr. Priest also announced that, as U. S. Representative on the International Colorimetry Committee of the I. C I., he would be pleased to receive any American comment on Mr. Guild's proposal relative to the adoption of values of the "excitations" to be accepted as standard in colorimetrics; and that, with this end in view, he would be glad to supply a complete copy of the document to anyone interested in this subject.

Deane B. Judd **Bureau of Standards**

EXTENSION OF THE O.S.A. "EXCITATION" CURVES TO INTERVALS OF ONE MILLIMICRON BY FIFTH-DIFFERENCE OSCULATORY INTERPOLATION

It has been shown that[1] the O.S.A. "excitation" curves do not differ seriously from distribution curves embodying the much more extensive and reliable measurements by Wright. This proof of the substantial accuracy of the curves which have been used tentatively for colorimetric computation for nearly 10 years suggests the likelihood of their continued use for, perhaps, a similar period.

Considerable inconvenience in past attempts to derive by means of these curves the dominant wave length and colorimetric purity of color stimuli has resulted because of difficulty in obtaining reproducible interpolated values; for example, the large discrepancies found by Priest[2] between the values computed by the three forms of Ives' formulas for purity were shown to be due to interpolation difficulties by Judd[3] who described computational procedures for minimizing the result of errors of interpolation.

In order to make possible the reproducible computation of dominant wave length and colorimetric purity, the O.S.A. "excitation" curves have been extended to intervals of one millimicron between 410 and 670 mμ by the method of osculatory interpolation. Each curve is represented as a series of parabolas of the fifth degree which join at the specified values (at every 10 mμ) so as to have a common first derivative and a common second derivative at the junction point. Sufficient accuracy has been maintained in the computation of these interpolated values to yield a basis for the computation of dominant wave length reproducible to one one-hundredth of a millimicron.

Bibliography:

[1] Comparison of Distribution Curves Embodying Wright's Recent Results with the O.S.A. "Excitation" curves, J.O.S.A., *21*, p. 434; 1931.

[2] Irwin G. Priest, The Computation of Colorimetric Purity, J.O.S.A. & R.S.I., *9*, p. 517; 1924.

[3] Deane B. Judd, The Computation of Colorimetric Purity, J.O.S.A. & R.S.I., *13*, pp. 133–152; 1926.

Deane B. Judd **Bureau of Standards**

A NEW SET OF DISTRIBUTION CURVES FOR USE IN COLORIMETRIC COMPUTATION

Although the O.S.A. "excitation" curves represent average, normal vision with fair accuracy[1] they possess a number of minor defects which lead to considerable inconvenience when they are used in colorimetric computation. It is possible that the time is now ripe for the cor-

rection of these defects. Accordingly a set of distribution curves has been derived from data (Wright and Gibson-Tyndall) published since the compilation of the O.S.A. "excitation" curves which have the following advantages for use in colorimetric computation:

(A) The new set of curves embodies the macular pigmentation corresponding to an average of 36 observers; the O.S.A. curves, to 2 or 3 observers.

(B) The new set of curves embodies the mixture data corresponding to an average of 10 observers, each of which yielded nearly identical results when the individual differences due to macular pigmentation had been eliminated; the O.S.A. curves embody the mixture data of 3 observers; part of the observations of one observer, which disagreed widely from those of the other two, were rejected.

(C) The new curves are smooth; the O.S.A. curves are somewhat irregular and require special treatment for finding interpolated values.[2]

(D) The new set of curves embodies the visibility function adopted as standard by international agreement; the O.S.A. curves are only approximately consistent with the standard visibility.[3]

(E) The luminosity coefficients referring to the new set of curves are: $L_r=1$, $L_g=0$, $L_b=0$; those referring to the O.S.A. curves are: $L_r=0.370$, $L_g=0.617$, $L_b=0.012$. It is evident that any computations involving the use of luminosity coefficients (such as computation of transmission, reflectance or colorimetric purity) will be considerably simplified if the new set of distribution curves be substituted for the O.S.A. "excitation" curves.

The only disadvantage in supplanting the O.S.A. curves by the new set of curves is the rather considerable inconvenience entailed by the change, itself.

Bibliography:

[1] Comparison of Distribution Curves Embodying Wright's Recent Results with the O.S.A. "Excitation" Curves. this program.

[2] Extension of the O.S.A. "Excitation" Curves to Intervals of One Millimicron by Fifth-Difference Osculatory Interpolation, this program.

[3] Proc. Int. Commission on Illumination, 6th meeting, Geneva, pp. 67 and 232; July, 1924.

Deane B. Judd **Bureau of Standards**

EXTENSION OF THE STANDARD VISIBILITY FUNCTION TO INTERVALS OF ONE MILLIMICRON BY THIRD-DIFFERENCE OSCULATORY INTERPOLATION

The two empiric representations (Tyndall-Gibson[1] and Walsh[2]) of the visibility of radiant energy yield curves which fail to pass exactly through the values at every 10 mμ adopted as standards;[3] hence, they can not serve as means of obtaining interpolated values. By the method of osculatory interpolation the visibility function is represented as a series of parabolas of the third degree which join at the specified values so as to have a common first derivative at the junction point. The discontinuities in derivatives of higher order which exist at the junction points are sufficiently small to be of no consequence.

Bibliography:

[1] E. P. T. Tyndall and K. S. Gibson, Visibility of Radiant Energy Equation, J.O.S.A. & R.S.I., *9*, p. 403; 1924

[2] J. W. T. Walsh, Visibility of Radiant Energy Equation, J.O.S.A. & R.S.I., *11*, pp. 111–112; 1925.

[3] Proc. Int. Commission on Illumination, 6th meeting, Geneva, pp. 67 and 232; July, 1924.

Loyd A. Jones and R. E. Burroughs **Kodak Research Laboratories**

THE ACTION OF LOW SPEED ELECTRONS ON PHOTOGRAPHIC EMULSIONS

Electrons from a heated cathode are accelerated by a potential V to an anode containing a slit. The electron beam passing through the slit was focused by a magnetic field on the photographic emulsion being studied.

The experiments performed brought out the following facts. No electron impacts were recorded when the electron beam was not distinctly defined by a visible radiation from the residual gas. The lowest voltage electrons recorded in each case was the lowest voltage electron that would produce a visible radiation in the residual gas of the electron tube. The lowest potential V which would cause the electron to produce a photographic blackening was determined by the composition of the residual gas and its pressure and in no way indicated that it was related to a characteristic of the photographic emulsion. The conclusion is drawn that the exposure produced on a photographic emulsion is not due to the sensitive grain receiving the electron's energy directly, but is due to the radiation excited by impacts of the electrons with the residual gas.

Bibliography:

K. Cole, Phys. Rev., *28*, pp. 781–792, Oct., 1926.
P. H. Carr, R.S.I., *1*, p. 711, Dec., 1930.

The present paper will appear in full in J.O.S.A.

Fred E. Wright **Geophysical Laboratory**

OPTICAL METHODS FOR REDUCING THE EFFECTS OF PHOTOGRAPHIC PLATE GRAIN

In the measurement of the positions of spectral lines or star images or other details on photographic plates the large silver grains of the negative are disturbing elements detrimental to accuracy. The obtrusiveness of these grains can be decreased by causing the image points of adjacent grains to overlap and merge. Dr. J. A. Anderson of Mt. Wilson Observatory recently accomplished this object by mounting a cylindrical lens above the objective of the observing microscope, thereby elongating each image point into a line. These image lines coalesce, in the case of a spectral line, into a continuous dark line on which good position settings can be made. For star images the method is not applicable. Other methods may, however, be used that depend, in principle on a reduction in the resolving power of the imaging system. This reduction can be effected by producing first a minified image and then viewing the minified image through a microscope. For a given separation of the grains the necessary amount of minification to destroy resolution can be computed, for an objective of known numerical aperture, on the basis of the diffraction theory. The results obtained by this minification-magnification method are gratifying. The same method can be used to eliminate the grains in a half-tone print. Another method is to reduce the aperture of the observing microscope by means of an iris diaphragm in the rear focal plane of its objective. For spectral lines a slit aperture in place on the iris diaphragm decreases the resolving power along the spectral lines but maintains the full aperture of the objective normal thereto. For faint spectral lines the use of dark-ground illumination, obtained by placing a suitable central stop in a microscope condenser lens, is advantageous. In this arrangement the spectral lines appear as bright lines on a gray background. The observations may be made either in natural or in polarized light.

The present paper will appear in full in J.O.S.A.

Saturday Afternoon, 2 o'clock
Columbia University

Herbert E. Ives **Bell Telephone Laboratories**

METHODS OF PROJECTING PARALLAX PANORAMAGRAMS

The problem of projecting pictures to exhibit stereoscopic relief can be solved in either of two ways. (1) Projection upon any "ordinary" screen of two pictures, taken from two points of view, with provision *at the eyes of the spectators* of means for distributing separate views to each eye; (2) projection of two or more pictures, taken from different points of view, upon a screen so constructed that the distribution of the views to the spectator's eyes is brought about

by some special construction of the screen. For the latter method to provide stereoscopic vision to any observer, wherever situated, it is necessary that the picture projected be a panoramagram,[1] rather than a stereogram, that is, it must consist of an infinity of views.

Three forms of screen have been devised for projecting parallax panoramagrams. The first is built up of transparent rods with front and back convex cylindrical surfaces. The front surfaces are of such curvature as to accurately focus parallel rays upon the back cylindrical surfaces. The latter are given a diffusing finish, and the parallax panoramagram (as made by a moving lens camera) is projected upon them from the rear, each strip of the panoramagram accurately registered upon a rod. The screen then displays a stereoscopic image through a wide angle of observation.

The other two designs of screen are intended for use with panoramagrams made at a single exposure by means of a large lens or concave mirror. These pictures have the component elements in the panoramic strips so disposed as to give pseudoscopic instead of stereoscopic relief,[2] and are unsuited for projection on the first type of screen. In order to transpose the elementary strip images, optical screen elements are used which form virtual images of the projecting lantern lens. One such screen, for reflected light projection, consists of polished, horizontally ribbed cylinders, in which the reflected images of the lens appear as narrow lines of light each cylinder having one of the picture strips projected upon it. The other screen consists of concave cylindrical grooves cut in a sheet of transparent material such as celluloid. These grooves function for transmitted light in a manner similar to the reflecting cylinders just described.

Bibliography:

[1] J.O.S.A., Dec., 1928, p. 435.
[2] J.O.S.A., June, 1930, p. 332.

Arthur C. Hardy and O. W. Pine **Mass. Inst. Technology**

AN ANALYSIS OF THE ERRORS IN THE USE OF INTEGRATING SPHERES

An investigation is made of the errors resulting from the finite size of the sample and the illuminating and observing apertures in integrating spheres.

The present paper will appear in full in J.O.S.A.

L. E. Dodd **University of California**

ADAPTION OF ABBE REFRACTOMETER WITH COMPENSATING PRISMS FOR READING REFRACTIVE INDICES FOR ANY MONOCHROMATIC LIGHT

With a given liquid and the compensating prisms set for achromatism the scale of an Abbe refractometer customarily reads directly the index of refraction for sodium light. It is possible to read indices for any other available single wave lengths by setting the prisms at other than the achromatization reading if use is made of suitable calibration formulae. The situation is analyzed in the present paper. Such formulae both general and special are derived.

Bibliography:

Abbe, 1874.
Wien and Harms, 1929.

The present paper will appear in full in J.O.S.A. & R.S.I.

Roger S. Estey **Electrical Testing Lab.**

THE ISOLATION OF ERYTHEMAL RADIATION

The width of the transmitted band of a monochromator is controlled primarily by the exit slit and to a lesser extent by the entrance slit, while the abruptness of wave length cutoff is controlled primarily by the entrance slit and to a lesser extent by the exit slit. The shape of the transmitted curve can be definitely stated in terms of a slit factor defined by the relation

$$\text{slit factor} = \frac{\text{wave-length range transmitted with full intensity}}{\text{total wave-length range transmitted}}$$

Assuming as an approximation, linear dispersion over the width of either slit, for slits set at the same width the slit factor can be shown to be ⅓. This means that for any total wave-length range transmitted, the intensity rises uniformly from zero to a maximum during the first third of the wave-length interval, remains at a maximum over the second and returns uniformly to zero at the end of the interval.

This principle has been applied to the isolation of the region represented by the 2967A maximum of the erythema curve in the following way. Keeping the entrance and exit slits of equal width, the slit widths and wave-length adjustments of a monochromator have been set so as to bring the extreme limits of the transmitted band to the wave lengths 2900A and 3050A. This transmitted band so obtained was verified by a quartz spectrograph placed behind the monochromator. The similarity between the resulting transmission and the erythema curve is indicated in the following table.

Wave length	Monochromator transmission	Erythema response		
		Hausser & Vahle[1,2]		Luckiesh, Taylor and Holladay[3]
		1922	1927	
3342	0.00	—	0.00	0.00
3132	0.00	0.045	0.00	0.025
3024	0.58	0.58	0.70	0.35
2967	1.00	1.00	1.00	1.00
2925	0.55	—	—	0.25
2894	0.00	0.30	0.34	0.10
2804	0.00	0.28	0.063	0.04

Bibliography:

[1] Hausser & Vahle, Strahlentherapie, *13*, 41 (1921).
[2] Hausser, Strahlentherapie, *28*, 25 (1928).
[3] Luckiesh, Taylor and Holladay, J.O.S.A., *20*, 423 (1930).

This method permits the integral value of erythemal radiation of any source to be obtained in one measurement and gives a much closer approximation to the erythema curve than do the usual filter methods.

E. Q. Adams **Lamp Development Laboratory, General Electric Company**

AN ANALYSIS OF HAUSSER AND VAHLE'S DATA ON ERYTHEMA

The recent work on the function of ultraviolet irradiation in forming the antirachitic Vitamin D has awakened renewed interest in the health-giving properties of radiations of shorter wave length than the visible spectrum, and in photo-erythema, the reddening of the skin produced by exposure to such radiations.

Hausser and Vahle have published results on the erythemal effectiveness of mercury radiation. These have been analysed by the method customarily applied to the blackened photographic plate. In their results degree of erythema was determined by comparing the color of the reddened skin with dyed paper standards. The paper colored with the maximum concentration of dye corresponded in color to eighth degree erythema. One-half the concentration of dye gave seventh degree; one-quarter, sixth; one-eighth, fifth, etc., fractions of degrees being estimated. In this analysis it was found by trial that plotting the square root of dye concentration against logarithm of exposure producing the erythema gives lines straight within the experimental error. From such straight line relations the effectiveness of radiation of various wave lengths in producing different degrees of erythema has been determined.

In photographic work the plate density varies with time of development. In a somewhat analogous way, the degree of erythema varies with time after exposure, rising to a maximum and then subsiding, with or without pigmentation.

The foregoing results apply strictly only to the results of monochromatic radiation but by connecting points for the various wave lengths by a smooth curve they have been extended to sources of continuous radiation. No quantitative experimental work seems to have been done on combinations of two or a small number of different wave lengths and the results with very complex mixtures of radiation do not readily lend themselves to analysis. In default of experimental knowledge, in this analysis the "addition theorem" approximately valid in photographic work has been assumed for erythema: the "addition theorem" namely, that to produce any given density (degree of erythema) the ratios of the intensity at each wave length to the intensity necessary to produce the given density (degree of erythema)—when that wave length is acting alone—must sum up to unity.

B. T. Barnes and W. E. Forsythe
Lamp Development Laboratory, General Electric Company

ERYTHEMA DUE TO ULTRAVIOLET RADIATION

The results of the anlysis of Hausser & Vahle's erythema data given in the preceding paper by E. Q. Adams have been used to calculate for different sources the relative effectiveness of the radiation in different spectral regions and the total erythemal effectiveness. With a bare quartz mercury arc the lines at 2480 and 2537A are found to produce the major part of the effect for intensities of reddening ranging from the threshold to the third degree. For more intense erythema the lines in the neighborhood of 3000A are responsible for most of the action. When the intensities of the lines of wave lengths shorter than 2700A in mercury arc radiation are sufficiently reduced, as in the case of the General Electric and Uviarc Sunlamps, the lines at 2967 and 3024A are of most importance even in producing the threshold of erythema.

The erythema produced by radiation from a tungsten filament at 3024°K in a quartz bulb is largely due to ultraviolet of wave lengths between 2450 and 2600A when the reddening is very slight. With higher degrees of erythema the radiation in the neighborhood of 3000A produces the major part of the action. In either case the spectral distribution curves for the erythemal effectiveness have two maxima, one near 2537 and the other near 2967A. Radiation from the sun directly overhead (transmitted through one atmosphere) has its maximum erythemal effect at about 3060A but over one-half the effect is found to be due to radiation of wave lengths longer than 3100A. Taking as a unit the time necessary for the sun's radiation through one atmosphere to produce erythema of the first degree the exposure times for various other sources have been computed. Results are shown in the table below.

Relative lengths of exposure necessary at 1 meter distance

Degree of reddening	Sun through one atm.	Sun through window glass	Bare uviarc 72.5 V. 3.75 A.	G. E. sunlamp	500 W. lamp quartz bulb	500 W. lamp corex D bulb
0	.90	—	.020	.28	10	47
1	1.00	22.	.066	.44	25	67
4	1.31	—	1.07	.90	120	140

G. Failla and P. S. Henshaw **Memorial Hospital, New York**

THE RELATIVE BIOLOGICAL EFFECTIVENESS OF X-RAYS AND GAMMA RAYS

Both x-rays and gamma rays are capable of producing certain biological effects. The relative amounts required to produce the same effect in a given medium depend first of all on the way in which quantity of radiation (usually called "dose") is defined and measured. The international unit of quantity of x-radiation, *the roentgen*, adopted in 1928 is based on ionization in

free air. In practice to comply with the requirements of the definition of the roentgen, it is necessary to measure x-rays by means of a large ionization chamber through which passes freely a narrow pencil of rays.

Theoretically it is obvious that the roentgen can be used also as a unit of gamma radiation. However, the experimental procedure is fraught with many practical difficulties and so far no direct measurements of gamma rays in roentgens have been published. On account of the importance of the problem from both the theoretical and practical points of view, the authors have attacked this problem in the only way which is capable of giving unequivocal results—that is, by developing an apparatus which fullfils the requirements of the definition of the roentgen, without questionable assumptions.

Having done this it became possible to compare the biological effectiveness of equal doses of x-rays and gamma rays expressed in roentgens. As a biological test object wheat seedlings were used. Extensive experiments with this material had brought out previously several important advantages: (1) Simplicity of technique, (2) reproducibility of results with reasonable precision, (3) biological changes could be observed simultaneously in cells having widely different radiosensitivities, (4) time required between irradiation and observation of results is relatively short, (5) doses required to produce a measurable effect are not unduly large. Nevertheless in order to irradiate the seedlings both with x-rays and gamma rays under strictly comparable conditions it was necessary to use four grams of radium.

The results obtained cannot be summarized briefly but will be given in full in the paper.

The present paper will appear in full in *Radiology*.

THE OPTICAL SOCIETY OF AMERICA

Purpose and Scope

The Optical Society of America is a national organization founded in 1916. Its aim is to provide an association of all those interests in any way connected with optics. It therefore serves a need which is not met by organizations in the separate sciences, for while it is vitally concerned in stimulating work in experimental and theoretical optics, it is equally interested in all the borderlands of optics. The experimental psychologist and the physiologist find the society active in physiological optics as witnessed by its sponsoring of a translation of Helmholtz and by such committee reports as those on Visual Sensitometry and on Photometry and Illumination. The biologist, working in fields overlapping optics, finds members of the society at work on the biological effects of radiation. The chemist finds similar common interests. In short, the aim of the society is to invite to its membership not only those who are contributing to the advance of fundamental optics but all those who, whether working in neighboring fields of science or in the industries, are active in the various applications of optics.

The Optical Society of America is, moreover, the official organization of optics in America and, as such affords representation to its membership in such international congresses as are called from time to time for the specification of optical standards.

The work of the society is accomplished largely through its meetings, the work of its committees, and its journals. The place of the annual meeting is not fixed. It is held, on invitation, in various cities and thus gives local stimulation to the interests of the society. In recent years it has been customary to hold a joint meeting with the American Physical Society in New York about the end of February. In addition to the papers offered at these meetings in which members report original work, there are usually several invited papers in a selected field. The general surveys thus afforded form an increasingly important service which the society is rendering.

Some idea of the work of the various committees of the optical society may be gained by examining the list of reports which is given below. It is suggested that even to those quite familiar with its work that a rereading of this list of committee activities will furnish one of the best possible statements of the purpose, scope and accomplishments of the society.

REPORTS OF COMMITTEES ON TECHNICAL AND SCIENTIFIC SUBJECTS.

(All references are to the Journal of the Society)

Visual Sensitometry—J.O.S.A., *4*, pp. 55–79, Mar., 1920.
Colorimetry—*4*, pp. 186–187, May, 1920.
Photometry and Illumination—*4*, pp. 230–235, July, 1920.
Lenses and Optical Instruments—*4*, pp. 236–238, July, 1920.
Pyrometry—*4*, pp. 305–336, Sept., 1920.
Instruments and Methods of Radiometry (Section of Report).—*5*, pp. 259–268, May, 1921.
Spectroradiometry—*5*, pp. 269–278, May, 1921.
Standard Wave Lengths—*5*, pp. 308–332, July, 1921.
Pyrometry, 1920—*5*, pp. 494–512, Nov., 1921.
Standard Wave Lengths—*6*, pp. 135–139, March, 1922.
Colorimetry—J.O.S.A. and R.S.I., *6*, pp. 527–596, Aug., 1922.
On Proposed Translation of Helmholtz (Also list of subscribers.)—*6*, pp. 659–661, Aug., 1922.
Spectroradiometry (Section)—*6*, pp. 1016–1029, Dec., 1922.
Refractometry (Partial Report, Color Correction of an Achromatic Doublet.)—*10*, pp. 39–63, Jan., 1925.
Spectrophotometry—*10*, pp. 169–241, Feb., 1925.
Physical Optics—*10*, pp. 549–560, May, 1925.
Color Terminology (Partial Report, Number of Answers received and Request for Better Cooperation.)—*11*, p. 44, July, 1925
Radiometry and Photometry—*11*, pp. 357–369, Oct., 1925.
Photographic Intensity—*12*, pp. 567–586, June, 1926.
Physical Optics—*12*, pp. 587–611, June, 1926
Color Terminology Questionnaire (Final Report.)—*13*, pp. 43–57, July, 1926.
Physical Optics—*14*, pp. 103–124, Feb., 1927.
Physical Optics—*16*, pp. 44–61, Jan., 1928.
Physical Optics (Supplementary)—*16*, pp. 301–306, May, 1928.

PUBLICATIONS OF THE SOCIETY

The Optical Society of America regularly publishes two journals. The Journal of the Optical Society of America, published monthly, is the official organ of the Society and is devoted to the science of optics in all its branches and applications in physics proper, in other sciences, as well as in industry. It is the purpose of the Journal of the Optical Society to present new and original contributions to optics and from time to time to present summaries of important developments to date in fields where such summaries would serve a useful purpose.

In collaboration with the Association of Scientific Apparatus Makers of America, the Optical Society publishes the Review of Scientific Instruments, a monthly journal devoted to instruments of all kinds—mechanical, thermal, and electrical, as well as optical. Contributors to this journal comprise investigators in research laboratories in the colleges and universities of the country, in the government and other similar laboratories and in industrial laboratories devoted to both test-

P. G. Nutting
1916–1917

F. E. Wright
1918–1919

F. K. Richtmyer
1920

J. P. C. Southall
1921

Leonard T. Troland
1922–1923

Herbert E. Ives
1924–1925

W. E. Forsythe
1926–1927

Irwin G. Priest
1928–1929

Past Presidents of the Optical Society of America
1928–1929

The Frederic Ives Medal

This medal, endowed by Dr. Herbert E. Ives in 1928, is named in honor of his father, Frederic Ives, distinguished for his pioneer contributions to color photography, photoengraving, three-color process printing, and other branches of applied optics. It is to be awarded by the Optical Society of America for distinguished work in optics. It is expected that the award will generally be made biennially on the occasion of the second annual meeting in each administration. Awarded in 1929 to Professor Edward Leamington Nichols.

No in "Annual" Series	*Date*	*Place*	*President*	*Secretary*	*Publication of Minutes*
1	Dec. 28, 1916[2]	New York	Nutting	Ross	J.O.S.A., *1*, p. 45; Jan., 1917.
2	1917[2]	(Meeting called for Pittsburgh was cancelled on account of war.)			
3	Dec. 27, 1918[2]	Baltimore	Wright	Nutting	Science, *49*, p. 52; Jan. 10, 1919. (See also J.O.S.A., Jan.-March, 1919.)
4	Feb. 26–27, 1920[1]	New York	Wright (Actg.)	Nutting (Actg.)	J.O.S.A., *4*, pp. 80–82; March, 1920.
5	Dec. 27–29, 1920[2,3]	Chicago	Richtmyer	Foote	J.O.S.A., *5* pp. 210–212; March, 1921. Science, *53*, pp. 318–320; April 1, 1921.
6	Oct. 24–26, 1921[4]	Rochester	Southall	Priest	J.O.S.A. & R.S.I., *6*, pp. 407–415; June, 1922. Science, pp. 501–502; Nov. 18, 1921.
7	Oct. 25–28, 1922	Washington	Troland	Priest	J.O.S.A. & R.S.I., *7*, pp. 59–102; Jan. 1923. Science, pp. 636–640; Dec., 1, 1922.
8	Oct. 25–27, 1923	Cleveland	Troland	Priest	J.O.S.A. & R.S.I., *8*, pp. 21–45; Jan., 1924. Science, pp. 451–452; Nov. 30, 1923.
9	Oct. 23–25, 1924	Boston	Ives	Richtmyer (Actg.)	J.O.S.A. & R.S.I., *10*, pp. 283–297; March, 1925.
	Feb. 27–28, 1925[3]	New York	Ives	Richtmyer / Southall (Actg.)	J.O.S.A. & R.S.I., *11*, pp. 125–134; Aug., 1925.
10	Oct. 29–31, 1925	Ithaca	Ives	Richtmyer (Actg.)	J.O.S.A. & R.S.I., *12*, pp. 473–494; May, 1926.
	Feb. 26–27, 1926[3]	Montreal	Forsythe	Richtmyer (Actg.)	J.O.S.A. & R.S.I., *13* pp. 303–308; Sept. 1926.
11	Oct. 21–23, 1926	Philadelphia	Forsythe	Bidwell	J.O.S.A. & R.S.I., *14*, pp. 133–148; Feb., 1927.
	Feb. 25–26, 1927[3]	New York	Forsythe	Bidwell	J.O.S.A. & R.S.I., *14*, pp. 470–476; June, 1927.
12	Oct. 20–22, 1927	Schenectady	Forsythe	Bidwell	J.O.S.A. & R.S.I., *16*, pp. 113–123; Feb., 1928.
	Feb. 24–25, 1928[3]	New York	Priest	Bidwell	J.O.S.A. & R.S.I., *16*, pp. 329–335; May, 1928.
13	Nov. 1–3, 1928[5]	Washington	Priest	Bidwell	J.O.S.A. & R.S.I., *18*, pp. 143–286, March, 1929.
	Feb. 22–23, 1929[3]	New York	Priest	Bidwell	J.O.S.A. & R.S.I., *18*, pp. 441–446, June, 1929.
14	Oct. 24–26, 1929[6]	Ithaca	Priest	Tuckerman	J.O.S.A., *20* pp. 139–172, April, 1930.
15	Oct. 30–Nov. 1, 1930	Charlottesville	Jones	Tuckerman	J.O.S.A., *21*, pp. 137–153, March, 1931.
16	Feb. 26–28, 1931[3]	New York	Jones	Tuckerman	J.O.S.A., *21* pp. 431–442, June, 1931.

[1] This meeting was originally scheduled to be held with A.A.A.S. in St. Louis, Dec. 1919, but was postponed on account of railway strike.
[2] With A.A.A.S.
[3] Joint meeting with American Physical Society.
[4] Helmholtz Memorial Meeting.
[5] Michelson Meeting.
[6] Thomas Young Memorial Meeting.

ing and research. In addition to such articles describing new improvements in instruments, methods of measurement or technique, the Review publishes frequently summaries of the developments to date in important fields of measurements. The Review includes also abstracts of important papers dealing with instruments or methods of measurement which have been published in other current journals.

Previous to 1930, these two journals were published as a single journal under the title of Journal of the Optical Society of America and Review of Scientific Instruments. The importance however of the instrument section of the combined journal became such that it was found advisable, beginning with January 1930, to publish it as a separate journal.

Through these journals the Optical Society, it is felt, is making very substantially an important contribution to science. Since January 1922, the Society has published in this way approximately 12,300 pages of scientific matter.

Under the auspices of the Society, there was prepared under the editorship of Professor J. P. C. Southall, an English translation of the third edition of Helmholtz's classic work on Physiological Optics. This work has had a wide distribution.

A committee of the Society prepared a report on colorimetry which report was reprinted from the Journal and sold separately. The demand for this report was such that the edition is now exhausted.

ORGANIZATION

PATRONS

(The payment of One Thousand Dollars toward the expenses of the society entitles the donor to the rank of Patron.—By-Laws, art. 2, sec. 1. See also J.O.S.A. and R.S.I., *8*, p. 38; Jan., 1924.)

Adolph Lomb
Eastman Kodak Company

OFFICERS AND EXECUTIVE COUNCIL
1930–1931

(The executive council consists of the president, the vice-president, the secretary, the treasurer, the past president, the editor-in-chief of the JOURNAL, the assistant editor-in-chief and business manager of the JOURNAL, as *ex officio* members; and four members at large elected by the society. Terms expire December 31, 1931 except as otherwise noted. For addresses, see alphabetical directory of membership.)

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Secretary—L. B. Tuckerman (Term expires December 31, 1935)
Treasurer—Adolph Lomb

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Editor-in-Chief—Paul D. Foote
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(Term expires December 31, 1933)

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A. H. Compton
I. C. Gardner
P. E. Klopsteg
E. D. Tillyer

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H. E. Ives
C. W. Keuffel

Case School of Applied Science, Inauguration of William Elgin Wickenden
W. E. Forsythe

Pharmacopoeical Society, Washington May 14, 1930
I. G. Priest, Chairman
Charles Bittinger
K. S. Gibson
A. C. Hardy
Dean B. Judd
A. H. Pfund

National Research Council Division of Physical Sciences
I. G. Priest

Council of the American Association for the Advancement of Science
H. E. Ives
F. K. Richtmyer

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(Any person who has done eminent service in the advancement of optics is eligible to honorary membership. The executive council may elect honorary members by unanimous vote.—By-Laws, art. 1. By action of the council, the President of the Optical Society, London, is *ex officio*, an honorary member of the Optical Society of America during his term of office as President of the London Society.)

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ALPHABETICAL DIRECTORY OF MEMBERS
(May 21, 1931)

R	indicates	Regular Member, dues paid annually.
RL	"	Regular Member, dues paid for life.
A	"	Associate Individual Member.
AC	"	Associate Corporation Member.
H	"	Honorary Member.

The number prefixed to each name is the serial number in order of election to membership. It gives the reference to the original record of election in the Society's archives.

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BANERJEE, Gyanendra Nath 851 A
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BANERJI, S. N. 560 A
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BAYLEY, Paul L. 619 A
Department of Physics,
Lehigh University,
Bethlehem, Pa.

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Hirschberg, Leo
Hotaling, Elmer E.
Hunt, Franklin L.
Ives, Herbert E.
Jensen, Axel G.
Johnson, John B.
Johnsrud, A. L.
Kanolt, C. W.
Kingsbury, Edwin F.
Kunz, George F.
Little, William F.
Logan, Henry L.
Macbeth, Norman
Maltby, Margaret E.
Marrison, W. A.
Millar, Preston S.
Mitchell, Dana P.
Müller, Ralph Holcombe
Newcomer, Harry S.
Pegram, George B.
Pooler, Louis G.
Powrie, John H.
Pupin, M. I.
Ranger, R. H.

Reynolds, F. W.
Rose, J. L.
Ryer, E. Leroy
St. John, Ancel
Schmid, Fred
Sette, William J.
Severinghaus, Willard L.
Sharp, Clayton H.
Southall, James P. C.
Spencer, Roy C.
Traeger, Alfred
Treleaven, Clifford L.
Webb, Harold W.
Williams, Horatio B.
Woll, Frederic A.

NIAGARA FALLS
Vincent, Mrs. Mabel S.

PAINTED POST
Gage, O. A.

POUGHKEEPSIE
Carter, Edna
Wick, Frances G.

RIVERDALE
Failla, G.

ROCHESTER
Altman, Fred E.
Bandoly, Erich
Bausch, Carl L.
Bausch, Edward
Bausch & Lomb Opt. Co.
Berry, William
Bishop, Fred M.
Bugbee, L. Willis, Jr.
Burroughs, Robert E.
Chapman, A. K.
Clark, Herbert A.
Eastman, George
Fairbanks, Floyd C.
Foster, Leon V.
Frederick, C. W.
Hall, Vincent C.
Hickman, Kenneth C. D.
Higgins, Frederick L.
Ingalls, Arthur L.
Jones, L. A.
Kingslake, Rudolf
Kurtz, Henry F.
Kurtz, John C.
Levin, Aaron
Lomb, Adolph
Lowry, Earl M.
Mees, C. E. Kenneth
Newton, A. J.
Nitchie, Charles C.
Noyes, Bradford, Jr.
O'Brien, Brian
Rayton, Wilbur
Schoen, Arthur L.
Seemann, Herman E.
Sheppard, S. E.
Silberstein, Ludwik
Taylor, A. M.
Tomkins, F. A.
Trivelli, A. P. H.
Tuttle, Clifton M.
Vaeth, William C.
Wilkins, T. R.
Wilsey, Rex B.
Wollensak, John C.

SCHENECTADY
Benford, Frank
Dushman, Saul
Koller, Lewis R.
Rice, C. W.
Snoddy, Leland B.
Wold, P. I.

SYRACUSE
Porter, R. A.
Randall, Dorus P.

TROY
Patterson, Robert Alexander

YONKERS
Arthur, John M.

NORTH CAROLINA

CHAPEL HILL
Stuhlman, Otto, Jr.

OHIO

AKRON
Dieterich, E. O.
Householder, F. F.

CLEVELAND
Adams, Elliot Q.
Albright, John G.
Forsythe, W. E.
Hodgman, Chas. D.
Miller, Dayton C.
Luckiesh, M.
Spencer, Charles Douglas
Stickney, George H.
Taylor, A. Hadley

CLEVELAND HEIGHTS
Holladay, Lewis L.

DELAWARE
Stetson, Harlan True
COLUMBUS
Blake, F. C.
Hesthal, Cedric Edward
Russell, Howard W.
Smith, Alpheus W.
DAYTON
Brachman, Nathan H.
Burka, Samuel M.
GAMBIER
Cottrell, Casper L.
IRWIN
Roots, Yale Kirby
MARIETTA
Phillips, T. D.
Watson, Arthur Clinton
NEWARK
Rolph, Thomas W.
OBERLIN
Taylor, Lloyd W.

OKLAHOMA

NORMAN
Nielson, J. Rud
Schriever, William

OREGON

CORVALLIS
Weniger, W.

PENNSYLVANIA

ASPINWALL
Bishop, F. L.
BETHLEHEM
Bayley, Paul L.
Bidwell, Charles C.
Ewing, Maurice
Larkin, Charles R.
BRYN MAWR
Helson, Harry
CHARLEROI
Macbeth, George D.
CLARION
Rizer, Conrad K.
DENVER
Wehr, M. R.
DREXEL HILL
Pond, Samuel E.
DUQUESNE
Kroeger, Wm. J.
EASTON
McQuarrie, W. C.
JENKINTOWN
Kerr, C. H.
MEADVILLE
Ling, Charles J.
MEDIA
Steiner, O.
PALMERTON
Haslam, George S.
PHILADELPHIA
Arnold, J. P.
Bazzoni, Charles B.
Behr, Leo
Brady, E. J.
Bronk, Detlev Wulf
Dike, Paul Harrison
Fulweiler, W. H.
Gray, Arthur W.
Harrison, T. R.
Ives, F. E.
Kaspereit, Otto K.
Leeds & Northrup Co.
McFarlin, John Robert
Myers, J. W.
Razek, Joseph
Richards, Horace C.
Stehle, Charles Gormley
Stewart, Thomas S.
Stokely, James
Thomas Co., Arthur H.
Thwing, Charles Burton
PITTSBURGH
Burns, Keivin
Chenault, Roy L.
Foote, Paul D.
Hower, Harry S.
Johnson, H. M.
Nathanson, Jonas B.
Rashevsky, Nicholas P.
Rupert, F. F.
Ruark, Arthur Edward
Sieg, L. P.
Smith, William Ogden
Taylerson, Ewart S.
Tillotson, E. Ward
Venable, William Mayo
Walters, Francis M., Jr.
Worthing, A. G.
READING
Hettinger, Edwin L.
STATE COLLEGE
Davey, Wheeler P.
Ham, W. R.

SWARTHMORE
Bramley, Arthur
Maxwell, Louis R.
Swann, W. F. G.
SWISSVALE
Grondahl, L. O.
TOWANDA
Swindells, Frank E.
UPPER DARBY
Holst, L. J. R.
WEST CHESTER
McCorkle, Paul
WILKINSBURG
Baud, Robert Victor
Ulrey, Dayton

RHODE ISLAND

NEWPORT
Eppley, Marion
PROVIDENCE
Farnsworth, H. E.
Palmer, A. de Forest

SOUTH CAROLINA

COLUMBIA
Mercer, Charles F.

TENNESSEE

NASHVILLE
Slack, Francis G.

TEXAS

COLLEGE STATION
Silvey, O. W.
DALLAS
McDonald, Frank C.
HOUSTON
Hartley, Kenneth
Ricker, Norman
Weaver, Paul
Wilson, Harold Albert
LUBBOCK
George, E. F.
SAN ANTONIO
Finch, Elmer H.

UTAH

PROVO
Marshall, Milton

VIRGINIA

CHARLOTTESVILLE
Beams, Jesse W.
Brown, Frederick Lyons
Geldard, Frank Arthur
CLARENDON
Saegmüller, F. B.
RICHMOND
Loving, R. E.
UNIVERSITY
Hoxton, L. G.
Sparrow, Carroll M.
WILLIAMSBURG
Merrymon, William Walter

VERMONT

BURLINGTON
Holmes, R. M.

WASHINGTON

COLLEGE PLACE
Kretchmar, G. G.
SEATTLE
Henderson, Evelyn C.
SPOKANE
Soltau, David L.
TACOMA
Seward, Raymond S.

WEST VIRGINIA

HUNTINGTON
Welch, George B.
MORGANTOWN
Colwell, Robert Cameron
Molby, Fred A.

WISCONSIN

MADISON
Ingersoll, L. R.
Jordahl, Olaf M.
Mendenhall, C.E.
Roebuck, John R.
Sproull, Wayne T.
Stebbins, Joel
MILWAUKEE
Poetker, Albert H.
WILLIAMS BAY
Moffitt, G. W.

2. FOREIGN MEMBERS ACCORDING TO COUNTRY

AFRICA (SOUTH)

Alden, Harold L.

ARGENTINA

Williams, Adolpho T.

NOVA SCOTIA

Henderson, George H.

CANADA

Allen, Frank
Ames, Arthur John
Dawes, H. F.
DeLury, Ralph E.
Foster, Alice W.
Gilchrist, L.
Hamer, Richard
Harrington, E. L.
Ireton, H. J. C.
Jacobsen, R. C.
Keys, David A.
Landon, Fred
McLennan, John C.
Robertson, J. K.
Ruedy, Richard
Shrum, G. M.
Young, R. K.

CHINA

Chao, Siu-Hung
Chu, Chih Teih
Hu, Kang Fu
Lee, John Y.
Supao, Ting

ENGLAND

Cheshire, R. W.
Curtis, William Edward
Dymond, E. Gilbert
Fleming, A. P. M.
Merton, Thomas R.
Renwick, F. F.
Smith, T.
Storr, B. V.
Turner, W. E. S.
Twyman, Frank
Wright, W. D.

FRANCE

Fabry, Ch.
Long, B.
Pieron, Henri

GERMANY

Baud, Robert Victor
Bielicke, Wm.
Harting, Hans
Hase, Rudolph
Jentzsch, Felix
Lang, Robert J.
Lewis, Lester C.
Pirani, Marcello
Yao, Yu Tai

HOLLAND

Bruin, T. L. de
DeGraff, Antonius

INDIA

Banerjee, Gyanendra Nath
Banerji, S. N.
Raman, C. V.

JAMAICA

Hamilton, George H.

JAPAN

Kakinuma, Usaku
Matsuda, C.
Nakamura, Saburo
Numakura, S.
Nurnberg, Roy Charles A.
Sigiura, Yoshikatu
Takamine, Toshio
Yamauti, Ziro

MEXICO

Brenner, M. E.

PANAMA

Oldach, W. H.

RUSSIA

Joffè, A.

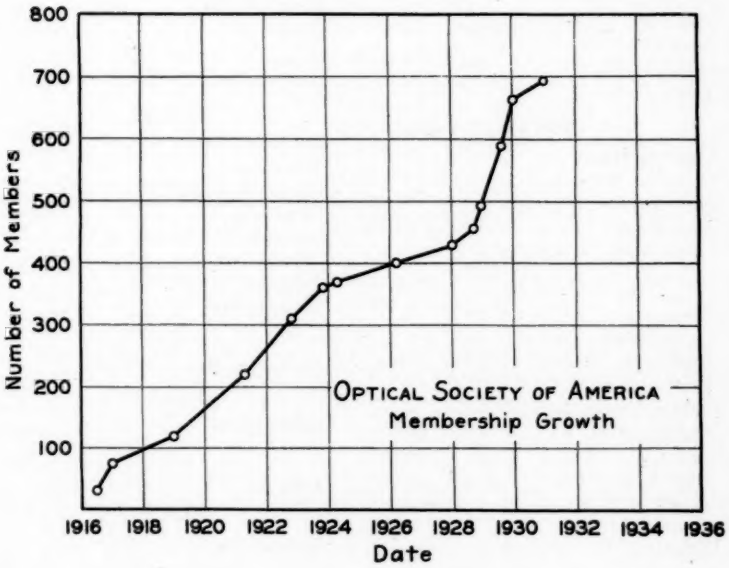
SWEDEN

Waldner, Axel

SWITZERLAND

Summers, H. D.
Turrettini, Edmond
Weigle, Jean Jacques

NUMERICAL SYNOPSIS OF MEMBERSHIP

(May 21, 1931)

Honorary	6
Regular	
Annual payment	424
Life payment	8
Associate individual	
Annual payment	259
Life payment	None
Associate corporation	15
Total	712